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AGRICULTURE

IN SOME OF ITS RELATIONS WITH

CHEMISTRY

BY

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AGRICULTURE.

CHAPTER XIV.

NITROGENIZED ANIMAL AND VEGETABLE REFUSE.

It will be noticed that the nitrogenous fertilizers described in the foregoing chapters are all "active," as the term is, i.e. they are easily assimilable by plants and are capable of serving directly as plant-food. But there are various other nitrogenous substances employed as manures which are much less active and are not at all capable, perhaps, of feeding plants until after they have undergone changes by way of fermentation or decay and have been converted to the form of ammonia or of a nitrate, or of some other assimilable compound. It is noteworthy that several of the "organic nitrogen compounds," as they are called collectively, are slightly analogous to farmyard-manure in that their nitrogen gradually becomes available for feeding plants and that their fertilizing action is felt during several years. It is not impossible indeed that these points of resemblance to farm-manure may be the chief reason why some of the less active nitrogenous matters continue to be used in agriculture. For it has always been true that many old-fashioned farmers, accustomed solely to the use of farm-manure and to the getting of several crops from one good dressing of such manure, find it a difficult matter to bring themselves to the act of using and esteeming quick-acting fertilizers, like guano or nitrate of soda, which do their whole work in a single season and leave no residual strength behind. To such men, the use of farm-manure and of substances such as bone-meal, peat, or even flesh, or rags, seems to be less risky, or, as some might say, less wasteful, than the use of guano and nitrates; and it is true enough that, when judiciously managed, several of the organic manures may do very effective service. In hot countries, moreover, and especially in those subject to persistent rains, it is not improbable that there may often be a decided advantage in applying organic nitrogen to the land rather than nitrate-nitrogen.

Fish-Scrap.

It has long been customary in certain localities, to employ fishes of one kind or another for purposes of fertilization, and in recent years very considerable quantities of valuable nitrogenized manure have been procurable in commerce under the name of fish-guano, or fish-scrap, or fish-waste. There are two principal kinds of fish-scrap, viz. the Norwegian, which is supplied to the European markets, and the American, which is made and used in this country. The Norwegian article is to all intents and purposes dried fish, dessicated codfish so to speak, only that it contains more bone than ordinary dried fish, since it is prepared in some part from the heads and bones that accumulate as refuse in the places where fish are cured. 70 tons of it were exported from Norway in 1860 and 5500 tons in 1877.

The American fish-scrap, on the contrary, is a product obtained incidentally in the manufacture of oil from a coarse sort of herring, called the menhaden, or pogy (Alosa menhaden). In order to get their oil, the pogies are boiled in water to a porridge or thick soup, which is pressed in a mill, just as ground apples are pressed in the manufacture of cider. In this way, the oil that was contained in the flesh of the fish is squeezed out, together with most of the water. On standing, the oil rises to the surface of the expressed liquid, whence it is dipped off for sale, while the pomace or residue left in the mill is the fish-scrap. It is called "pogy chum" by the fishermen. Sometimes the pomace as it comes from the mills is pressed into barrels for transportation, at others it is dried in the sun, as in the making of hay from grass, and occasionally it is simply left in loose heaps to heat and dry out of itself. In rare instances it is dried artificially. When thoroughly dried and ground to a fine powder, it is sold as "fish-guano." But there is no evidence that this more expensive product is any better than ordinary pulverulent fish-scrap.

According to Rein, the Japanese also obtain oil and fish-scrap from several kinds of herrings which visit their coasts in great numbers. They spread out the pomace in fields to dry and send it into commerce either loose or pressed. They use the scrap for manuring tea-plants, and for hastening the growth of young cotton and tobacco, and prize it highly as a fertilizer.

The amount of water in American fish-scrap varies widely according with the different methods of treatment above mentioned. Ordinarily the sun-dried scrap contains 8 or 9 or 10 % of water; sometimes as much as 12 %. But 18 to 22 % have been noticed in merchantable scrap, and occasionally 30 or 40, or even 50 % of water have been met with in fresh scrap. It may here be said that in fresh herring Payen and Boussingault found 76.6 % of water, and 2.74 % of nitrogen, while in salt codfish they found 38 % of water and 6.7 % of nitrogen.

In this country, fish-scrap has hitherto been used for the most part by manufacturers of fertilizers for mixing with superphosphates, and the price paid for the scrap has commonly been determined solely by the quantity of nitrogen contained in it, which usually ranges from 6 to 8 %. But it will be well for the farmer to remember that the percentage of phosphoric acid in the scrap, viz. 6 or 7 %, is nearly as high as the percentage of nitrogen.

On the other hand, an analysis, by Arendt, of Norwegian fish-scrap gave of

	Per cent.
Moisture	17
Nitrogen	10½
Phosphoric acid	4
Organic matter	72
Ashes	11

Other samples have shown more phosphoric acid (13 to 15 %), and less nitrogen (8½ to 9 %). Some of them were of scrap that had been steamed to remove the oil.

The difference in composition between the Norwegian fish-guano and American pogy-scrap is readily explained by a reference to the facts that the two products are derived from different kinds of fishes, and that in the American method of manufacture the fish are boiled and pressed. Much nitrogen is contained of course in the watery liquor or soup which is pressed out with the oil and is necessarily removed from the scrap, though in large establishments, the soup is evaporated to dryness in its turn and put to use. The menhaden is a very bony fish withal, whence the high percentage of phosphoric acid in the American product.

Fish-Scrap a very Cheap Manure.

American fish-scrap, such as that above described, is an extremely cheap manure for some kinds of crops. It can usually be bought at wholesale for $12 or $15 the ton, and seldom or never costs more than $18. At these rates its fertilizing constituents come at very low prices, the nitrogen in particular costing less per pound than so good an article can usually be bought for in its other forms. The reason why this is so appears to depend on the rather unpleasant odor of the fish-scrap, which creates a prejudice against it in the minds of common carriers, and so hinders the transportation of small parcels of the material. In case the scrap costs $15 the ton, and that a ton contains 120 lb. of phosphoric acid, and that, for the sake of the argument, this constituent be held to be worth 5 cents the pound, then there would be $6 worth of phosphoric acid in the ton; so that, even if there be no more than 120 lb. of nitrogen in the ton, this constituent will be worth ($15 — $6 =) $9. That is to say, the pound of nitrogen will come at 13 cents.

Perhaps it would be fairer to argue that the material contained 7 % of nitrogen instead of 6 %, as in the foregoing calculation. But on the other hand, it is to be remembered that phosphoric acid should come very cheaply nowadays when bought in the form of phosphatic slag.

Fish-Scrap should be used as such.

Any farmer so situated that he can get profit by using fish-scrap should buy this cheap material directly from the fishermen, and use it as such, i. e. under its own name, instead of paying a comparatively high price for it, as is now often done after it has been admixed with superphosphates. I have myself found fish-scrap to serve extremely well as a substitute for barnyard-manure, when used in conjunction with wood-ashes or other potassic fertilizers. Fish-scrap is said to do its best service on light soils, and several European writers have urged that it may properly be applied in the autumn even for the use of summer crops which are to be sown in the next spring.

Worth of the Nitrogen in Fish-Scrap.

It is to be observed, however, that the nitrogen in fish-scrap, though often held by dealers to be worth 18 or 20 cents the pound, or as much as the nitrogen in nitrate of soda, is really much less valuable for the farmer, at least here in the Northern States. In our climate, the chief part of the fish-scrap cannot act so quickly as the nitrate would. More or less time is needed in order that the scrap may ferment and that the nitrogen in it may by this process be converted into ammonium salts or nitrates, or some other product assimilable by plants.

There is usually a small proportion of ammonia in the scrap, it is true, at the moment when it is applied to the land, though not much. On the other hand, there is no evidence that all the nitrogen in the scrap ever becomes available for plants in any climate. Herein is a great difference between true chemical compounds, like ammonium sulphate or like nitrate of soda, — each particle of the nitrogen of which is excellent, and as good as any other particle, — and organized substances, such as fish, or flesh, or vegetable matters, some of the nitrogen in which may indeed easily become available for feeding plants, while other portions are always liable to remain totally unfit for this purpose.

Recent experiments by S. W. Johnson have shown that a larger proportion of the nitrogen in freshly cooked menhaden is in an easily soluble and decomposable condition than of that contained in the dried and ground product sold as "fish-guano." Indeed, ordinary menhaden scrap, as obtained from the fishermen, is better in this respect than the more thoroughly dried product. The process of drying appears in some way to impair the solubility of the nitrogen in the scrap.

It is noticeable that in the American fish-scrap a more considerable part of the value may be credited to phosphoric acid than is the case with the Norwegian product. Thanks, moreover, to its mechanical condition, and to the fact that it has been cooked, it appears to be a manure of rather quicker action than the Norwegian scrap.

As with the meal of steamed bones, so with fish; it is a reasonable inference that their flesh may act more quickly as a manure after having been cooked. This fact appears to be enforced by some field experiments made by Heuser, who applied steamed and plain Norwegian fish-scrap to a strong, well-drained, but raw and crude loam, from which the surface soil had recently been removed. The crop was barley, and it grew much more luxuriantly where the steamed scrap had been applied. Heuser argues that the advantage lay in the easier decomposition of the steamed product, and not in any superiority as regards the amounts of nitrogen or phosphoric acid contained in it. There were harvested from the hectare the following crops, in kilos: —

	Grain.	Straw.
No manure (mean of two plots)	709	3,799
Plain fish-guano	1,297	4,367
Steamed fish-guano	1,704	5,032

Norwegian Scrap is now made in this Country.

Fish-manure similar to the Norwegian article is even now manufactured to some extent here in New England, and the amount could undoubtedly be increased largely if there were any quick demand for the finished material. Thousands of tons of worthless fish are captured every year at the fishing stations, that is to say, fish like whiting, skates and sculpins, dog-fish and other sharks, which have no merchantable value, to say nothing of good fish that become tainted in hot weather, or of the waste portions — heads, fins, entrails and bones — of cod, haddock, halibut, and the like. It is neither a difficult nor a costly matter to dry and grind these waste fish whenever the farmers care enough for the product to make it worthy any one's while to prepare it.

More than this, very large quantities of the worthless fish might readily be caught on purpose, if there were any sufficient demand for fish-scrap to make them worth the catching. Those now caught are caught against the fisherman's wishes, — in spite of him, in fact. There is a never-failing supply of fish in the sea, where there is an almost infinite amount of room, and where man has small power to annihilate, or even to thin out, the migratory fishes.

Fish-Scrap Cheaper than Night-Soil.

It is not improbable that in the future, when the increase of population shall enforce a more intelligent agriculture, the drying of fish-scrap may become an important branch of industry. It bears even now very curiously upon the question of utilizing the sewage of cities. The reproach has often been made, that the modern system of removing filth from cities by means of water-closets and sewers flowing to the ocean is wasteful, unphilosophical, and wrong. But it appears from what has just been said, that such censure is hasty and ill-considered. So long as a clean, innocuous, and concentrated manure can be got from the sea, in the shape of fish-scrap, at less cost of money, comfort, labor, health, and life even than would have to be expended in transporting the city filth to the farm, or in converting it into transportable form, it would be mere folly for the farmers to waste their energies upon the sewage.

In speaking thus of "health and life," reference is had, of course, to diseases traceable to stagnant sewage, and to the various ills which may arise from the storing of excremental matter about houses, or from using it upon fields.

It is evident that, so long as nitrogen and phosphoric acid can be obtained more cheaply in the shape of fish-scrap than they can be got from the filth of cities, the question of removing this filth does not even come within the domain of agricultural inquiry. It remains a civic and a sanitary question merely, and has little or no interest for the farmer.

There are localities, no doubt, as is the case with many inland cities, where the sewage must eventually be carried to the land in some way, simply because there is no other outlet for it; but even here it has often been found to be cheaper to precipitate and disinfect, to filter and aerate the foul water than to apply it directly to land on which crops are growing.

The Question of Salting Fish.

To illustrate how entirely the possibility of using any manure must depend upon the cost of getting it, it might be suggested that, beside the method just now alluded to, of drying fresh fish caught upon the spot, some system of salting those caught at a distance from the fishing-towns could readily be devised, so that the factories of fish-guano should be supplied from a wider area. And to this end cheap chloride of potassium from Stassfurt could perhaps be used to replace common salt, so that potash as well as nitrogen and phosphoric acid would be contained in the fish-guano, which would thus become a less special manure than it now is. Indeed, fish-scrap thus salted could be classed as a complete manure. But it is evident that the question whether any such plan could ever be put in practice must depend upon considerations as to whether the product so obtained would be worth to the farmers as much as the cost of bringing it to them. The answer seems plain, that fish thus salted cannot be used as manure because the cost of getting them would be very nearly as large as the cost of getting ordinary edible salt-fish. It is still true, however, that comparatively cheap materials may be discovered fit for preserving fish for fertilizing purposes; and, in any event, the cost of drying such fish would be low. It was in fact suggested, some years ago, that fish might readily be kept fresh for three or four days by sprinkling them with a solution of ferric chloride or of ferric sulphate, strong enough to mark 45° Beaumé. An amount of the iron solution equal to 5 % of the weight of the fish was used, and the fish were crushed, pressed and dried in due course. In the case of oily fish, the dried product was leached with naphtha, to save the grease.

Of late years, the saving of fish-waste for agricultural purposes tends slowly to increase. There is a constant demand for it on the part of the manufacturers of the so-called ammoniated superphosphates and of formula fertilizers, i. e. mixtures compounded on the basis of the composition or supposed needs of any given crop. Factories of fish-guano, on the Norwegian plan, were established long ago by Frenchmen on their islands near Newfoundland. There are several such factories here in Massachusetts, though the owners of some of them appear to find it more profitable to operate upon the flesh of whales than upon that of fish proper. So, too, as Nordenskiold noticed, the Norwegians bring the carcasses of whales from Spitzbergen to the guano factories on the Norwegian coast.

Krocker has analyzed whale-guano, in comparison with ordinary fish-guano, as follows: —

	Norwegian Whale-Guano.	Norwegian Fish-Guano.
Moisture	5.35	9.84
Organic and volatile matters	62.35	56.18
Ash ingredients	32.30	33.98
	100.00	100.00
Nitrogen	7.63	8.50
Phosphoric acid	13.45	14.84
Lime	16.49	15.96
Magnesia	0.15	0.94

Considerable quantities of cod and haddock scrap, and of waste fish-also, are saved, however, both at the factories on Cape Cod and at Gloucester, on Cape Ann. The prices of several kinds of fish-waste are quoted every day in the reports of the Gloucester fish market. For example, when pogy-scrap is held at $12 the ton, fish-waste is cited at $9, and liver-scrap at $6. This liver-scrap is sometimes sold at prices as low as $3 or $4 the ton at Gloucester. It is the refuse from fish-livers that have been boiled and pressed to remove their oil. It is a rather soft and somewhat sticky product. Hitherto it has seldom cost more than $12 the ton at Gloucester. (Gregory.) A sample examined in England by Voelcker contained 26 % of moisture, 24 % of organic matter, 37 % of insoluble silicious matter, 2.33 % of phosphate of lime, and 1.7 % of nitrogen.

A sample of fish-waste, sold at $16 the ton at Gloucester, contained: —

Water expelled at 212° F.	8.25 %
Nitrogen	7.00 %
Phosphoric acid	6.50 %

It consisted of skins, fins, and back-bones, with more or less flesh attached, as taken from salted cod and haddock that are to be packed in boxes and sold free from skin and bone. An analogous product, as cut from half-cured fish, but not dried by artificial heat, could be bought at Gloucester, at that time, at $3 or $3.50 the ton.

Long ago, Payen and Boussingault found $6\frac{3}{4}$ % of nitrogen in salted codfish that had not yet been dried, and contained 38 % of water; and almost 17 % of nitrogen in codfish that had been washed and pressed, and dried in the air, so that it contained only 10 % of water.

On the coast of Maine, more or less of the refuse from herring and mackerel that are canned or packed as sardines is saved nowadays, beside great quantities of the menhaden refuse, as above mentioned.

Fish-Scrap needs to ferment in the Soil.

It is to be noted that almost the whole of the nitrogen in dried fish is in the form of organic compounds, which need to undergo decomposition or fermentation in order that the nitrogen may be made available as plant-food. To this end, moisture, warmth and air are necessary; and these conditions may be fulfilled by burying the fish-scrap not too deeply in a mellow soil, in warm, but not too dry weather. It has been said in Europe, that while fish-scrap, applied in late summer or early autumn, is a good manure on light land for wheat and for rye, it has little significance when applied in the spring for barley or for spring wheat. It is claimed that, in our Southern States, fish-scrap generally gives a better account of itself than it does at the North; and the idea is probable enough, because of more rapid production of ammoniacal products through decay, and of quick nitrification subsequently.

Indeed, Kellner has recently shown that in the hot, moist climate of Japan, fish-scrap and bone-meal are really quick-acting and powerful nitrogenous manures. In comparative experiments, where the fertilizers were used upon a light, volcanic soil, and were applied to barley in the autumn, at the time of sowing, and all at once, both the fish and the bone did better service than sulphate of ammonia or than night-soil. The ammoniacal manures were rapidly changed to nitrates which were washed out of reach of the roots of the crop by rain, and it was noticed that even the virtue of the fish and the bone was exhausted in six months' time, so rapidly did nitrification run its course under favorable climatic conditions. So, too, in rice-fields, where the fish-scrap, etc., acted by virtue of the ammonia produced by their decomposition. Kellner remarks that, in warm countries of abundant rainfall, easily assimilable nitrogenous fertilizers have far less significance than in cold and temperate lands, for the high temperature and abundant moisture so favor the decomposition of organic matters that their fertilizing action is quickly felt, and there is no need of using the more costly nitrates and ammonium salts.

In view of the different climates of France and England, it was perhaps not unnatural that the French should have prepared and used fish-scrap to a considerable extent some years before the English paid much attention to it. In like manner, it would appear that woollen rags were formerly held in special esteem in France, though it is true that they were freely used in some parts of England, also, for certain kinds of crops.

Manifestly, it would neither be wise to use Norwegian fish-scrap as a top-dressing, nor to plough it under very deeply, for in both cases the necessary fermentations would be interfered with. So, too, on close, heavy clays, and on cold ground in early spring, there would be small reason to expect quick profits from fish-scrap; but when applied to Indian corn, on good mellow land, it might do superexcellent service in warm, summer weather. Probably the best way of using fish-scrap in temperate climates is in conjunction with not very heavy dressings of farmyard manure, or in conjunction with live wood-ashes, if they can be got.

Fish-Waste preserved by Lime.

A method of saving fish refuse by means of lime, which was employed long ago in France by Hérouard, may perhaps be worthy of being put in practice sometimes by farmers living in localities where worthless fish are obtainable at certain seasons. The plan was, to mix in a hogshead tub, layer by layer, quicklime and the offal obtained in cleaning fish. The lime will slake by virtue of the moisture of the fish waste, and at the same time the latter is said to be disaggregated. On throwing the mixture into heaps, and finally forking it over, a powdery product is obtained. Manifestly, the lime combines chemically with the flesh to form an albuminate of lime, as it were, which is a body little liable to putrefaction or change when dry. Indeed, the limed fish may be kept as well as fish that has been salted and dried.

There are several familiar examples of analogous compounds of lime and organic matter. In domestic economy, broken crockery is sometimes mended by a cement prepared from lime and milk, or lime and cheese; and there is a process of calico-printing, in which inert coloring matters are fixed upon the cloth by causing casein and lime to combine upon them to form a product insoluble in water which clings firmly to the cloth, — caseate of lime it might be called.

Scum of Sugar-houses.

In the processes of sugar-making and sugar-refining, lime is added to the cane (or beet) juice, and to solutions of brown sugar also, to clarify them. It acts by combining with and rendering insoluble various albuminous and mucilaginous substances, which, if they were left in the juice, would be apt to injure it by bringing about changes and fermentation of the sugar. There is obtained in this way a considerable amount of waste product known as "scum," which has a certain small value as a fertilizer, though the compact and adhesive condition in which it comes from the press is an objection to its use. Thanks to the great excess of lime in the scum it has a strong alkaline reaction, and it may in some localities be used with advantage for composting; one plan is to soak the material in water, to stir the mixture to the condition of thin mud, and to throw this liquid upon the peat or weeds or other matters which are to be composted. One advantage in covering the scum with earth is that the earth hinders ammonia from escaping as it would do if the scum were left to ferment by itself. On this account it is well also to plough under the scum speedily in case it is applied directly to the land.

In some localities, where stiff clay soils are near at hand, the scum has been applied to them directly with advantage. Dehérain mentions a French farm where the scum is applied at the rate of 22 tons to the acre. Its mode of action in this instance resembles that of lime, the clay being made mellower and less plastic than it was originally.

Sugar-scum consists chiefly of carbonate of lime and of lime in combination with organic matter, though some of the lime is still caustic. That from beet-sugar factories is said to contain usually from 1 to 2 % of phosphoric acid, and about 0.25 % of nitrogen, though the analyses show wide variations. For example: 30 to 40 to 50 % or more water, 10 to 20 % or more of organic matter, 20 to 40 % or more of ashes, 18 to 24 % of lime, 0.1 to 0.9 % of nitrogen, 0.5 to 1.3 % or more of phosphoric acid, and 0.1 to 0.2 % of potash. A. Mayer reports 0.2 % of nitrogen and 0.6 % phosphoric acid in Dutch samples; and he remarks that in cases where phosphoric acid is used in the diffusion process the scum will naturally contain considerable quantities of phosphate of lime. Riffard found in scum obtained on adding lime to juice as pressed out from sugar-cane 11.70 % of protein, and 14.46 % of ashes, which consisted of 6.16 lime, 3.83 phosphoric acid, 0.85 oxide of iron, 1.28 carbonic acid and 2.34 silica.

According to the U. S. Department of Agriculture, fresh press-cake from the scums of cane-sugar, as prepared from cane-juice, contain on an average 45 % of water, 15.7 % of ash, 3.5 % of phosphoric acid and 1.14 % of nitrogen, or, reckoned on the dry material, 28.56 % of ash, 6.33 % of phosphoric acid, and 2.10 % of nitrogen. As has been said, already, under bone-black, the scum from sugar refineries may contain considerable quantities of bone-black and of coagulated blood.

Chaptal noticed long ago that the soft scum, when taken directly from the vats and applied to the land, is apt to kill plants; but on leaving the scum for a year to ferment in heaps it is converted into a very powerful manure. As a rule, it is said that the safest way of using the press-cake is not to apply it in the spring while it is still fresh, but to use it in the subsequent autumn, after it has been kept long enough to "ripen." Latterly, sugar-scum tends to be neglected as a fertilizer, in Europe, because the effects obtainable from it can be got more conveniently by means of phosphatic slag; though there can be little doubt that there are many clayey soils where the scum would be useful when used in conjunction with farmyard manure.

The remark of Chaptal, in his Chimie Appliquée (I, 153), that lime forms insoluble compounds with almost all animal and vegetable substances that are soft, and thus destroys their power of fermenting, seems to have had no little influence in stimulating inventors to employ lime as above, and for preserving night-soil and clarifying sewage also, as will be explained hereafter.

One point remains to be noticed in respect to the nitrogenized manures other than ammonia and nitrates. A successful grower of tobacco has informed me that he gets a better flavored leaf when he manures the plants with fish-scrap, flesh, or blood, than when he uses nitrates or ammonium salts. Here is seen another reason, among many, in favor of using several varieties of manure at one and the same time.

Animal Refuse.

Beside fish-scrap, there are several other nitrogenized fertilizers of importance, notably dried blood, dried flesh, and some kinds of oil-cake.

All kinds of animal refuse are highly nitrogenized, and some kinds are valuable manures. Thus, there are several matters occasionally obtainable at the farm, such as the intestines of animals, bits of skin and flesh, sinews and the like, which are of value when properly composted with earth, and thus brought to a condition in which they can be subdivided and made available to the plant.

All the foregoing substances decompose readily in moist earth, and might be applied directly to the plant were it not for the difficulty of distributing them advantageously.

There is another set of substances, such as horn, hoofs, hair, wool, and woollen rags, bristles, feathers and leather, which though highly nitrogenized decompose so slowly in the earth that they are of comparatively little value when applied directly to the land. Some of them indeed are of no value whatever. In order to derive much advantage even from the best of them, they must either be allowed to ferment in the compost heap, in contact with dung or urine, or with powerful chemical agents such as ashes, or potashes, or lime; or they may be boiled in potash lye; or any of them might be subjected to destructive distillation, either alone or admixed with an alkali, for the sake of the ammonia which could be obtained in that way as a product of their decomposition.

As several chemists have remarked with regard to leather, it is not at all strange that this substance should decompose so slowly in the soil as to be practically worthless as manure, for it is a product that has been prepared specially and purposely to resist decay.

Voelcker insisted years ago, that there can no longer be the least doubt that the efficacy of the nitrogen which is contained in any given manure must be very materially affected by the form or state of combination in which this nitrogen exists. "Anyone who has tried side by side nitrate of soda, guano, and wool-waste must have felt surprised at the different degree of rapidity with which the effects of these three fertilizers are rendered perceptible in the field." Upon wheat, for example, nitrate of soda may make the young plants luxuriant and of dark green color in the course of 3 or 4 days, while with guano 8 or 10 days may be needed to produce similar effects; and wool-waste may give no evidence of utility even after the lapse of 4 to 6 weeks, though when the grain comes to be threshed out some increase may be noted.

Torrefied Leather.

It has often been thought that the fertilizing power of leather, or the like, might be improved by subjecting it to heat strong enough to disorganize it, and make it crumbly and friable, without actually destroying it. In point of fact, much leather-scrap is actually treated in some such way as this for the purpose of recovering the oily matters which were introduced into the leather during the process of currying it. There is small reason to doubt withal that the powdered product has been employed sometimes for the adulteration of nitrogenized superphosphates.

As Reichardt insisted some years since, leather-scraps when subjected to the action of hot steam in a close boiler become hard, dry, and brittle, and can then be readily reduced to the condition of a fine powder.

"Leather-meal," prepared in this way, has been somewhat used as a fertilizer in Europe, and has been found to differ from mere powdered leather in that, as shown by experiments, it has a certain small, though appreciable fertilizing power, while the original leather has none. Petermann found 7.51% of total nitrogen in meal from steamed leather, and noted that 0.43% was in the form of ammonia; there was 0.81% of phosphoric acid also. It appears also, from Morren's experiments, that leather-meal (from steamed leather) enters into putrefactive fermentation when moistened, and that the moist material evolves offensive odors when kept in a warm place. A small proportion of ammonia is produced, and considerable quantities of soluble nitrogenous compounds, though the amounts are less than those produced from torrefied horn-meal under similar conditions.

Instead of steaming leather-scrap in boilers, Coignet, in France, has employed the cheaper method of subjecting it, and other nitrogenous matters, to the combined action of steam and hot products of combustion from a coke fire. His apparatus is so arranged that the leather (or horn, or rags, or refuse from the glue-makers) shall be enveloped during several hours by a mixture of steam and chimney air at temperatures in the vicinity of 300° F. Under these conditions leather (or horn) swells somewhat, and becomes dry and friable without losing any of its nitrogen. Petermann found 6¾% of nitrogen and 14⅓ % of phosphoric acid in a sample that had been sold in Belgium as Coignet's fertilizer. It is evidently with reference to this process that the statement has recently been made, that certain manufacturers of fertilizers at Paris devote themselves particularly to the preparation of torrefied wool, horn, leather, and even bone, the latter having first been steamed strongly to remove oil and gelatine.

Morren has studied some of these torrefied products, and finds that the horn-meal speedily enters into putrefactive fermentation when kept moist. Some ammonia is produced during the putrefaction, as well as a quantity of soluble nitrogenous products. It was found that the horn-meal decomposed much more readily than the leather-meal, and that practical men prefer it to the leather-meal as a fertilizer.

Danguy's estimations of nitrogen in 14 samples of leather from different kinds of animals ranged from 4 to 7 %, and S. W. Johnson found that leather chips usually contain 5 to 8 % of nitrogen. He finds also that ammonia is given off from them copiously when they are boiled in strong potash lye.

Reichardt suggested some years since, that it might be well to treat the powdered leather-meal (steamed) with a weak solution of potashes, which, as he found, is capable of dissolving nearly one third part of the steamed leather. It should here be said, that, previous to 1860, the chemist Runge, in Germany, manufactured an artificial fertilizer upon a large scale by boiling leather scraps and woollen rags with a mixture of Glauber's salt and quicklime. S. W. Johnson reports an experiment in which powdered leather was heated with more than its own weight of oil of vitriol and the product was neutralized with carbonate of lime and then tested in pots of earth, in which Indian corn was grown, in contrast with other kinds of organic nitrogen. In this experiment, the nitrogen in leather thus treated was found to be as available as that in dry fish or in hoof- and horn-meal.

Composition of Blood and Flesh.

Lean flesh contains about 75 % of water, 3 to 4 % of nitrogen, 0.5 % of alkali salts, and 0.5 % of phosphoric acid; or in a ton, say 70 lb. of nitrogen and 10 lb. of phosphoric acid. After it had been dried in the air, Payen and Boussingault found in it 8.5 % of water and 13 % of nitrogen.

Fresh blood contains about 80 % of water, 2.5 to 3 % of nitrogen, 0.5 % of alkali salts, and 0.25 % of phosphoric acid; or in a ton, say 55 lb. of nitrogen and 5 lb. of phosphoric acid.

Dried blood is an article of commerce. It has long been prepared in France for exportation to the sugar-growing colonies, and has commanded a tolerably high price. According to Gasparin, more than 400 tons of it were sent from France to Guadeloupe in the year 1831. In 1856 Stoeckhardt told of its being sold at the rate of $3 or $3.50 the hundredweight.

Preparation of Dried Blood.

For obtaining dry blood there appear to be two methods of procedure. Either the fibrin alone of the fresh blood is made to coagulate, by some system of shaking or stirring, and the liquid serum is drawn off by itself and evaporated to obtain the albumen in it, which is valuable for use in the arts; or, more commonly, both the fibrin and the albumen in the blood are made to coagulate together by slightly acidulating the blood with sulphuric acid and blowing steam into it, while it is subjected to mechanical agitation. In this case the clot contains almost the whole of the nitrogen of the blood, and the watery liquor which separates from the clot is thrown away. But in either event it is the solid clot which, after having been dried and ground to powder, is sold as a fertilizer under the name dried blood or blood-meal. A litre of fresh blood is said to yield about 500 grams of clot, containing 170 to 200 grams of dry substance carrying 12 to 13 % of nitrogen. But in order to facilitate the drying of the clot, it is mixed with small quantities of other matters, whereby the proportion of nitrogen is reduced somewhat. As sent into commerce, the French product (dried blood) contains 13 or 14 % of water; 78 or 79 % of organic matter; 7 to 9 % of ash ingredients; about 12 % of nitrogen; from 1 to 1⅓ % of phosphoric acid; and about ¾ of one per cent each of potash and lime.

Ten samples of blood-meal examined at the Münster experiment station contained from 8½ to 13¼ % of nitrogen, or in the mean, 11¾%. Thirteen samples tested at Gembloux gave 11.23 as the mean percentage of nitrogen. It is not only a powerful manure in the chemical sense, but is in an excellent mechanical condition. It is dry, friable, and pulverulent, has hardly any odor, and may be transported and applied without trouble.

In this country dried blood is usually mixed with other fertilizers before coming to the farmer's hands. For example, it is said to serve extremely well as a "dryer" for some kinds of superphosphates which would be left damp and sticky unless something were added to them to correct a certain small excess of sulphuric acid which has to be employed in the process of manufacture. One very old plan was to mix blood and slaughterhouse offal, layer by layer, with enough sawdust to bring the wet material into manageable form. The moist product could either be ploughed under directly, or made into compost with peat or sods. Two loads of the blood-sawdust composted with three loads of loam were said to be sufficient for an acre of wheat. It was thought to be better suited for land of an open texture than for tough clays.

Dried blood containing as much as 10 or 12 % of nitrogen and from 10 to 20 % of moisture may still be procured in this country as a fertilizer, though in the article commonly sold as dried blood by the dealers in manures it has been more or less admixed with other kinds of animal refuse. Indeed, it is said by some manufacturers of fertilizers that it has been found impracticable to keep mere dried blood for any length of time unmixed; but that, when the blood is thoroughly mingled with dried pulverized meat, the two keep perfectly, with no perceptible loss of ammonia. Blood in its natural liquid state is a quick-acting manure which admits of being conveniently applied in horticulture. But care should be exercised that neither seeds nor young plants — not even potato sets — can come in contact in the soil with any considerable quantity of dried blood, or of fertilizers that contain blood, lest the seeds decay. It is best not to apply blood fertilizers in the drills or furrows, but to strew them broadcast and to work them into the soil thoroughly before the crop is planted. Highly favorable results are said to have been obtained in practice by watering young fruit-trees with a mixture of fresh blood and 10 or 12 times as much water.

Field Experiments with Dried Blood.

Petermann, in Belgium, has carefully tested the fertilizing power of dried blood, as compared with that of nitrate of soda, upon spring wheat, both on a clayey and a sandy soil. The experiments were made in quantities of earth amounting to 4 kilos, and there were added to this amount of soil the following quantities of fertilizers, either one at a time, two at a time, or all three at once, as stated in the table; viz. 0.25 grm. nitrogen, 0.3 grm. phosphoric acid, and 0.2 grm. potash.

NITROGEN ALONE.

Kind of fertilizer.	Clayey Soil.		Sandy Soil.	
	Grain.	Total Crop.	Grain.	Total Crop.
No manure	7.94	26.13	2.08	7.34
As dried blood . . .	19.56	62.07	5.05	15.75
As nitrate of soda . .	20.14	64.39	7.51	27.02
NITROGEN AND PHOSPHORIC ACID.				
N as dried blood . . .	19.51	62.41	8.94	29.40
N as nitrate of soda . .	19.62	64.58	9.76	31.12
NITROGEN, PHOSPHORIC ACID, AND POTASH.				
N as dried blood . . .	19.44	63.17	12.19	34.78
N as nitrate of soda . .	19.80	64.81	12.93	36.97

These results show clearly that the nitrogen of dried blood is a powerful manure. Although the nitrate of soda was superior, on the whole, to the blood, especially on the light land, the blood nevertheless did excellent service. The nitrogen both of the blood and of the nitrate of soda increased the number of stalks of wheat and the size of the ears; it increased the yield of grain threefold, and more than doubled the yield of straw. The blood gave decidedly better results than had been obtained in previous experiments from steamed wool-waste, and very much better than those got from crude wool-waste and from leather-meal. It will be noticed that the addition of phosphatic and potassic fertilizers to the nitrogenous did no good on the clay, though such additions were of considerable use on the light land. It has been reported, indeed, that Petermann has found that the wheat crop may be doubled on certain infertile sands in Belgium by the judicious use of dried blood.

In England, blood composts are said to be excellent top-dressings for either grain or grass, and dried blood mixed with bone-meal, or with a superphosphate, has often been found to do good service on turnips.

The nitrogen in dried blood is probably worth considerably less, pound for pound, than that in Peruvian guano, though of course it is worth very much more than that from less easily decomposable materials. In the opinion of some observers, the nitrogen in blood is worth twice as much per pound as that in coarse bone-meal.

Blood and Lime.

According to A. Mueller, any fresh blood which may happen to be at a farmer's disposal, either that of animals slaughtered at the farm or that obtained from a neighboring butcher, can be readily saved by mixing it with fine peat and lime. In illustration of this idea, he stirred 50 grms. of ground quicklime into 250 grms. of fresh blood, and added 32 grms. of fine peat-slack, to correct the pastiness of the mixture. The friable product was odorless, and it dried out quickly. In another trial, Mueller mixed 250 grms. of fresh blood with 58 grms. of peat-slack, and noted that the mixture was nearly odorless, and that the water in it dried out readily, to the extent of 71 % the weight of the blood. An older method of procedure was to use lime alone without the peat. The blood was thoroughly mixed in a shallow box with 4 or 5 % its weight of dry, freshly slaked lime; the mixture was covered with a thin layer of the lime, and left to itself to dry out. The dry mixture may be kept for a long while without change. It may be applied to the land as such, or it may be added to a compost-heap.

To test this matter, Heiden mixed 2,000 grams of sheep's blood with 130 grams of freshly slaked lime, and covered the mixture with a thin layer of the lime (1 %), and he found that the mixture solidified completely in the course of 24 hours. During the months of July and August, he left the mixture in a room where it was exposed to several hours' sunlight every day, but he could not perceive that it underwent any change excepting that the odor was a trifle less perceptible as time went on, and that a very hard crust formed on the surface that was not easily cut with a knife. Beneath this crust the material was less hard; it was black, and looked like undecomposed blood. Meanwhile more than half the moisture originally contained in the blood had disappeared.

Chandler's Scrap.

Several varieties of dried flesh may be procured from the dealers in fertilizers. One well-known product, called "greaves," or "cracklings," or "chandler's scrap," is obtained as a residuum in the rendering of tallow and the preparation of soap-grease. It consists of the membranous portion of the animal fat or suet, from which the tallow or fat proper has been separated by melting and pressing. These greaves occur in commerce in the form of large, compact cakes, like cheeses, which have been pressed very strongly. Payen and Boussingault found 8 % of water and 12 % of nitrogen in a sample which they examined.

Formerly it was no very easy matter to break up or pulverize one of these cakes, though by long soaking in water they could be broken down sufficiently to admit of the flesh being applied as a manure. Nowadays the cakes are made thinner and much more manageable. Perhaps one good way of pulverizing the cake would be to pare it down with a carpenter's drawing-knife? Greaves are said to have been used to a certain extent at one time, many years ago, by the manufacturers of superphosphates for reinforcing their products. They are used for feeding dogs in England, and poultry in this country. Sometimes they are given to swine, also.

More than a hundred years ago, an English writer, Hunter, insisted on the advantages to be gained by composting the refuse scrap left by whale's blubber from which the oil had been boiled out. This material might be described as a particularly foul variety of greaves. One plan was to lay down a bed of moor-earth a foot or more thick, to spread upon it a layer of equal thickness of long litter from horse-stables, and above that a layer of the whale-scrap. By repeating these layers, the heap was built up to a height of six feet, and was topped off with a thick covering of moor-earth. After the lapse of a month, the heap was forked over and again covered with earth, with the result that a second strong fermentation occurred. The operation of turning was repeated at proper intervals until the whole heap had become a uniformly putrid mass.

Before the cheaper kinds of slaughter-house refuse were to be had, damaged greaves offered a good material for fermenting peat in compost heaps, and they were on that account worthy the attention of farmers. But when in good condition greaves are worth too much as an article of fodder ever to be used as manure. There are many farmers in this country who might find their advantage in using this material for feeding hogs. Corn-meal by itself is too starchy and too little nitrogenous to be the best possible food for growing swine; and these chandler's scraps will supply just what the maize lacks.

Tankage.

Under the name of tankage, a kind of flesh-meal is prepared in this country from the refuse meat, entrails, and other offal that accumulate in slaughter-houses. These materials are steamed in tanks to remove grease, and the residue is heated by steam in a jacketed iron cylinder and stirred continually with hot rakes until it has become dry, and been reduced to a fine mechanical condition. When well prepared, this product should contain no more than 10 or 12 % of moisture, though sometimes it has been found to contain as much as 30 %. Usually it contains more water and more phosphoric acid, some 5 to 7 % namely, but less nitrogen, some 7 or 7½ %, than pure dried blood. Since much of the nitrogen in this material is easily decomposable, it is to be regarded as a valuable manure on land moist enough to encourage fermentation.

As has been stated under the head of blood, tankage should be thoroughly admixed with the soil before seeds are sown, lest it cause them to decay. It had better be applied broadcast and be harrowed in rather than to put it in the hills or furrows. One effect of tankage, which is true also of dried blood, dried fish and cotton-seed-meal, is that when mixed with a soil the rate of flow of water through that soil is greatly retarded. As will be stated under cotton-seed-meal, the surface tension of water is very considerably lowered by the presence of tankage and similar organic fertilizers, so that the capillary lifting power of soils charged with these materials may be lessened. Thus it happens that the injudicious use of concentrated organic matters in a dry season may "burn out" the land and make it drier than it would otherwise have been, although their judicious use in favorable seasons might tend to make the soil more retentive of the actual rainfall. (M. Whitney.) Other products from modern slaughter-houses, consisting of mixtures of blood, bone, and meat, dried and powdered, have been found to contain 5 or 6 % of moisture, and 11 or 12 % of nitrogen. In some cases a part of the phosphoric acid in this material is of manifestly poor quality, because it is contained in fragments of coarsely powdered teeth.

Flesh must Ferment.

It is to be remembered that flesh-meal and tankage, as well as fish-scrap, must undergo fermentation before the nitrogen in them can become available for crops, and that time enough must be allowed for the fermentation and the conditions be made favorable for it. When properly composted, either in heaps or in the soil itself, flesh-meal may do valuable service; but unless the conditions are proper and the fermentation occur at a suitable time the fertilizer can hardly be expected to yield any adequate profit. European experience teaches that crops grown the same year that flesh-meal has been applied as such to the land are apt to derive less benefit from this application than the crops of the succeeding year get from it. It has been observed also that flesh-meal applied in the autumn does more good to grain crops than when it is put upon the land the next spring. Dehérain observed that potatoes dressed with flesh-meal got no good from it whatsoever. On fodder-corn it did some good, while the fodder-corn of the next year did very well. Oats, however, grew well the very same year that flesh-meal was applied to them. Wheat sown in the autumn after the potatoes above mentioned grew well and yielded heavily, and it was noticed that the good effect of the former dressing of flesh-meal was felt by wheat-crops during several succeeding years.

Large quantities of flesh-meal from slaughter-houses at Fray Bentos, in Uruguay, where Liebig's extract of flesh is prepared, have been carried to Europe, and there used both as fodder and as manure. Beside residual flesh from which the juices have been extracted, this product contains blood, bone, tendons, etc., like many of the other kinds of flesh-meal. Analysis shows that it contains 5 to 7 % of nitrogen, and from 13 to 20 % of phosphoric acid. The manufacturers claim that it contains 6 % of nitrogen, and 16 % of phosphoric acid.

It may here be remarked that in silk-growing countries the larvae in the cocoons have long been esteemed as a powerful manure. It was the custom formerly, after the silk had been reeled off, to apply the cocoons to mulberries and other trees which were sickly and in need of refreshment. (Chaptal.) The refuse also from places where silkworms are fed is a powerful nitrogenous manure. It is a mixture of the dung of the worms and the framework of the leaves they have eaten, together with some dead worms. Boussingault and Payen found in it 11.4 % of water and 3.3 % of nitrogen. In the chrysalides of silkworms they found 78.5 % of water and 1.9 % of nitrogen.

Dissolved Flesh-Meal.

Some European manufacturers, by treating the South American flesh-meal with sulphuric acid, have prepared from it a fertilizer which contains about 12 % of soluble phosphoric acid; and their process might evidently be applied to tankage of any kind.

The French Chemist Girard has suggested, as a sanitary measure, that the flesh of animals which have died of contagious diseases might well be treated with cold, strong sulphuric acid, for the purposes of destroying germs and of saving fertilizing matters. He would put a quantity of sulphuric acid, of 60° Beaumé, into a wooden tub that has been lined with sheet lead, and would throw the carcass of the animal into this acid, piece by piece, taking care to keep the tub covered to hinder the acid from absorbing moisture from the air. A considerable amount of heat is set free by the action of the acid on the flesh, so that the fat melts and rises to the surface, whence it may be collected and put to use. It is said that, excepting hoofs and horns, which dissolve but slowly, no more than 24 or 36 hours are needed in order to disaggregate or "liquefy" an animal. According to Girard the action of the acid does not much slacken or become enfeebled until something like three-quarters of its own weight of flesh, etc., have been acted upon. After it has become saturated, so to say, with flesh, the acid may still be used to make superphosphate, by mixing it with ground rock phosphate, since it is well suited for this purpose.

It is to be noted in any event that the "solution" of flesh in acid can hardly contain any very large proportion of fertilizing matters for — as Girard estimates — 100 lb. of the original carcass may contain no more than some 2 lb. of nitrogen and 1.5 lb. of phosphoric acid, and when these constituents are commingled with the large quantity of acid they must necessarily be considerably diluted. In an experiment where 9 sheep weighing altogether 204 kilo. were dissolved in 500 kilo. of the acid, the product contained 0.722 % of organic nitrogen and 0.058 % of ammonia-nitrogen, beside half of one per cent of soluble phosphoric acid.

Girard suggests that, in case a process of this kind were to be employed at chemical works, or by municipal authorities, it might be well to provide apparatus competent to make use of hot sulphuric acid, and to thus obtain quicker action and a more concentrated "solution" of the flesh. If this were done, the final superphosphate would be proportionally richer in nitrogen, and would contain some ammonia, also, formed by the action of the hot acid on the flesh.

Flesh-meal.

Another kind of dried flesh is made in Germany from dead horses, and from cattle that have died of disease. It is sold expressly as a manure under the name of flesh-meal. One method of preparing it, as practised in Leipsic some years ago, has been described as follows. After having been skinned and opened, the horses were divided into four pieces, which were thrown into large iron cylinders arranged to act as Papin's digesters. Each of these cylinders was large enough to receive 3 or 4 horses at once, and in these receptacles the flesh was exposed to steam for 8 hours under a pressure of 2 atmospheres.

By this long-continued steaming, the whole of the fat in the carcasses is extracted, and all the tendons and sinews are changed to gelatine. Even the smaller bones of the animals are softened. When the steam is finally shut off, two layers of liquid are found in the digesters. The upper layer consists of soft fat, which has a well-established value in commerce. It is used for wheel-grease, for making soft-soap, and for preparing wool for spinning. The lower layer of liquid, on the other hand, is a soup; that is to say, it is a solution of glue contaminated with the so-called extract of flesh. It is evaporated to the consistence of syrup, and sold under the name "bone-size," to be used by weavers in preparing their thread for the loom. After the boiled flesh has been pressed, it is dried in a kiln, the bones are picked out, and the flesh is ground to powder by itself.

The factory at Leipsic had three digesters, and, by working day and night, could dispose of 16 or 18 horses in the course of 24 hours. Practically, it did use up some 1,500 horses, 150 cattle, and 500 hogs, dogs, and sheep, in the course of the year.

Another factory, a Rheydt, in the Rhine region, worked off annually from 1,000 to 1,200 head of horses, and a few hundred other animals, as well as several thousands of hundred-weight of refuse from slaughter-houses, such as the head and feet of sheep. The meal from this last factory has been analyzed by Karmrodt. He describes it as a yellowish, dry, and tolerably fine powder, having a slight odor of incipient putrefaction. It contained 8.68 % of N, and 7.53 % of P_2O_5.

At another factory of the same kind, near Linden, in Hanover, bones and dried flesh were ground up together. Hence, a larger proportion of phosphoric acid in the meal. From an analysis by

Wicke it appears that flesh-meal of this kind contains 6½ % of nitrogen, and 30 % of phosphates, which may perhaps amount to 14 % or so of phosphoric acid. Hirzel found in flesh-bone-meal from a factory in Munich, 7 % of moisture, 7.44 % of nitrogen, and 14.9 % of phosphoric acid. Wolff gives for average flesh-meal, as sold in Germany, 9¾ % of nitrogen, 6⅓ % of phosphoric acid, and 28 per cent of water.

Dried Garbage.

In many American cities it has long been customary to keep the offal from food ("kitchen waste") separate from the coal-ashes and other "dry dirt" which accumulates in houses, and to have it removed by special scavengers. Until recently, this "city swill" has been used for feeding hogs, but latterly suggestions have been thrown out in several localities that it had better be burned.

In the following plan, proposed by Fleischmann, and put into practice at Buffalo, the idea is to destroy all offensive and dangerous matters, by subjecting the garbage to a temperature high enough to disinfect it thoroughly, and at the same time to preserve intact the fertilizing constituents, and to recover grease, bones, rags, and other merchantable materials. To this end, some 5,000 lb., more or less, of the garbage are thrown into a jacketed cylinder, which is heated by steam under 80 lb. pressure, and are there stirred continually by means of a hollow rake — constructed of steam pipes, and kept full of steam at the pressure above-mentioned — which is made to revolve within the cylinder. By means of a fan, the vapor which arises from the garbage thus heated is drawn out into a special chamber, where it meets jets of spray, or sheets of water, and is speedily condensed. An amount of water equal to 60 % of the original weight of the garbage is thus removed from it, and is allowed to flow into the common sewer.

From the drier, the garbage passes into an automatic extractor, where the grease is dissolved out by means of benzene applied in such manner that one and the same quantity is used over and over again, continually, without loss. On being removed from the extractor, the material falls upon a series of screens, which sift out bones, rags, and other coarse substances, and there is obtained a dry, pulverulent fertilizer, rich in nitrogen and phosphoric acid, and readily salable. At Buffalo, on treating some 30,000 lb. of garbage per diem, there was recovered 1,800 lb. of grease and 12,000 lb. of the fertilizer. It is said that all the operations are odorless, and that the business pays a good interest on the investment.

Oil-Cake.

In order to obtain the oil which is contained in certain oily seeds, such as flax-seed, rape-seed, cotton-seed, or the like, it is customary to grind the seeds to powder, to place the meal in coarse bags that are laid between warm plates of iron, and to subject it to powerful pressure. After most of the oil has been expressed, a residuum known as oil-cake is left in the bags in the form of a thin, hard, flat cake; after having been ground, it is called oil-meal. Generally speaking, both oil-cake and oil-meal are worth so much for feeding animals that they should not be applied directly to the soil as fertilizers; but in countries where few cáttle are kept — notably in China, Japan, and the south of France — they have been largely employed as manures. Moreover, there are several kinds of oil-cake, such as those from the castor-oil bean, and from the physic-nut of the Cape de Verde Islands, which contain some purgative or medicinal principle, and are consequently unfit to be used as food for animals.

Castor Pomace.

Castor pomace is a merchantable product in this country, as that from the physic-nuts was formerly. At one time, considerable quantities of these nuts were expressed in Boston. Castor pomace usually contains some 5 or 6 % of nitrogen, about 2 % of phosphoric acid, and 1 % of potash. It is said that some tobacco growers believe that castor pomace has a particularly favorable effect on the quality of the tobacco-leaf, which cannot be produced by other nitrogenous manures, and that they prefer to pay a specially high price for nitrogen in this form.

As compared with other kinds of oil-cake, the value of a ton of castor pomace may be computed as follows: —

100 to 120 lb. of N at 15 cents	$15.00 to $18.00
40 lb. of P_2O_5 at 6 cents	$2.40
20 lb. of K_2O at 4½ cents	.90
	Say, $18.00 to $22.00

As with the other kinds of oil-cake, the large amount of organic matter contained in this material would count in its favor as against some kinds of artificial fertilizers upon gravelly soils that are not too dry. Care should be taken to keep castor pomace in places where animals cannot get at it, and the men who spread it should walk with the wind, for, though not poisonous, it is very disagreeable for the eyes and mouth. (Gregory.)

Linseed Cake.

Linseed oil-cake usually contains about 5 % of nitrogen, 1½ % of potash, and 2½ % of phosphoric acid. It is evident from these figures that it must be a much weaker manure than guano, with which it was thought worthy at one time of being compared. A ton of Chincha Island guano would have contained 2½ times as much nitrogen, 6 times as much phosphoric acid, and rather more potash even, than a ton of oil-cake. Hence, unless the price of oil-cake were considerably less than half the price of such guano, there could be no thought of using it directly as manure. To this day, rape-cake, and other kinds of oil-cake, are esteemed to be valuable manures by the Japanese, who use them to hasten the growth of young cotton and tobacco plants. Formerly, both rape-cake and linseed-cake were used directly as manure on good land in Germany and in England, with excellent results so far as appearances went. At first, as much as half a ton to the acre of broken rape-cake was used, but on pulverizing the cake, and drilling it in with the seeds, it was found that 500 or 600 lb. to the acre were sufficient, and 800 lb. came to be regarded as a heavy dressing in England. According to Gasparin, from 500 to 900 lb. to the acre are applied in the ordinary course of cultivation at the south of France, though for hemp as much as 1,400 or 1,500 lb. are used. He has himself had good success in starting lucern-fields and grass-fields on poor land which was manured with nothing but oil-cake.

Oil-Cake on Moist Land.

In England it was observed that oil-cake gave much better results in wet than in dry seasons, and it was held to be more serviceable on clays and other moist soils than on those which are dry. The broken or powdered cake decomposes readily in the earth, except in very dry seasons, so that no preliminary fermentation or composting was strictly necessary, though it was occasionally composted with thirty times its weight of farmyard manure. It was held to be a manure of quick and evanescent action, which seldom did much good to more than the single crop to which it was applied. It was often used by itself as a top-dressing for grain, or it was drilled in with wheat, at the rate of from 8 to 16 bushels to the acre. According to Hunter, rape-cake was much used on thin, calcareous soils in Yorkshire (England) towards the close of the last century. It was harrowed in with the seed-grain at the rate of 32 bushels to the acre for wheat, and at the rate of 24 bushels for barley. Some farmers preferred to mix the broken cake with loam, and to moisten this mixture to incite fermentation, in order to be sure of quick and regular action when the material was applied to the crops.

Lawes and Gilbert, in their field experiments with barley, applied to some plots of land nothing but rape-cake, year after year, at the rate of about 9 cwt. per acre per annum, and they obtained in this way crops which exceeded the average barley-crop of the country, though the yield was not quite equal to the maximum for the soil and the seasons, as obtained by means of farmyard manure or by mixtures of artificial fertilizers, supplying a somewhat smaller quantity of nitrogen than was contained in the rape-cake. The nitrogen in rape-cake nitrifies much more slowly than that in ammonium salts, and thus does not supply as much plant-food during the period of the active growth of barley as is supplied by nitrates or by ammonium salts; with the rape-cake, nitrification extends more evenly throughout the year, and nitrates are thus produced when they are not wanted (for the barley). The effect produced on the soil by rape-cake is said to have been well marked. In the course of years, the uppermost 9 inches of this soil came to contain a higher percentage both of nitrogen and of carbon than any other plots in the field, excepting only those dressed with farmyard manure.

In Flanders, oil-cake was mixed with much liquid manure, and suffered to ferment therewith before it was applied to the land. These fermentations were doubtless philosophical enough in the days that preceded the use of guano, ammonium salts, and nitrates; but nowadays the farmer can buy in these substances manures that act as speedily and as efficiently as the fermented cake, and which are more manageable and decidedly less troublesome. One reason why the composting was persisted in is found in the fact that heavy dressings of oil-cake, when applied at the same time with seed-grain, are apt to ferment so quickly and powerfully that the seed becomes involved in the process of decay, and is destroyed. Perhaps to this cause may be attributed the sentiment of French farmers, that it is inadvisable to apply oil-cake continually to any land which does not contain an excess of humus, unless the cake is used in conjunction with strawy manure, or in alternation with such manure. (Gasparin.)

Fermentations may Injure Crops.

As a general rule, no kind of fermentable organic matter should be put into the soil immediately in contact with seeds. Even after the application of bone-meal, it is well to wait a few days before sowing seeds, in order that the first hot fermentation of the bone may abate. In this point of view, it may be questioned whether the old plan of drilling in rape-cake together with seeds was wholly commendable. As Lawes has said, "Organic manures, as well as those which are chiefly nitrogenous, should never be concentrated near to the plant in its earliest stages of growth, but only within its reach, when, under the immediate influence of mineral manures, the young plant has so far developed its organs of accumulation and its healthy vigor as to be competent to grow faster than the natural atmospheric and soil resources of nitrogen and carbon enable it to do."

It has often been noticed in Europe that dressings of oil-cake are specially apt to do harm in case no rain should fall before the seeds have started or while the plants which have been dressed with the oil-cake are still young. To avoid this risk, it is customary at the south of France to wet the powdered oil-cake before applying it to the land, while in other districts the rule is not to sow grain until 10 or 12 days after applying the oil-cake. Two explanations have been offered to account for this injurious action: one idea is that in a dry time the oil in the fertilizer may smear the seeds and hinder them from germinating; while others have thought that perhaps the oil-cake may favor the multiplication of hurtful insects which molest the tender plants.

In general, the action of oil-cake, though somewhat slower than that of guano, was found to be quicker than that of bone-meal. The following experiment of Stoeckhardt will illustrate this point. The crop was oats grown on land that was fairly moist: —

	Fertilizer. Kilos to the Hectare.	Harvest. Kilos to the Hectare.	
		Grain.	Straw and Chaff.
No manure	...	928	1,213
Bone-meal	400	1,127	1,390
Bone-meal and Sulphuric acid	400 200	1,249	1,757
Rape-cake	400	1,872	2,387

On dry land there is no sense in using oil-cake anyway as a fertilizer; and on good land, except in very dry years, the chief part of the fertilizing effect of the cake is felt during the first season. German observers have estimated the effect at 50, 30, and 20, for the first, second, and third years.

Lawes insisted long ago that rape-cake and other organic manures have special significance for fertilizing turnips, an effect which he was inclined to attribute to the large amount of carbonaceous matter in the cake. Indeed, rape-cake was at one time a good deal used upon turnips in some places in England, and although there was an impression that it was not very well suited for the young and tender plant, it was thought to be excellent for turnips after the crop was once well started. Latterly it appears to have been superseded by superphosphate for this crop.

When applied to wheat in the experiments of Lawes and Gilbert, rape-cake seemed to do good only in proportion to the nitrogen that was contained in it. Thus, 100 lb. of the cake containing 5 lb. of nitrogen and 80 or 90 lb. of carbonaceous matter, gave no larger increase of grain than an ammonium salt which contained 5 lb. of nitrogen and no carbonaceous matter; but when applied to turnips the rape-cake had a decidedly beneficial effect and did much more good than the ammonium salt.

Rape-cake vs. Wire-worms.

Rape-cake has long been used in England as a means of protecting young wheat-plants from the attacks of the wire-worm. Thus it has been directed to "Apply to the land and plough or harrow well in 5 cwt. of rape-cake crushed into half-inch lumps. The wire-worms will congregate on these lumps of cake, devouring them with such avidity as to become glutted. They perish either from repletion or from the peculiar properties of the rape, or from the combined effects of the two causes. Rape-dust will not answer, because it presents no surface for the worms to fix themselves upon. . . Many of the lumps of cake examined were found full of the defunct and expiring worms." (Charnock.)

The idea is in some part supported by a practice adopted in English hop-gardens, where the wire-worm is apt to be a great pest, viz. to put pieces of cut potatoes in the soil, close to the hop-plant and on both sides of it, in order to attract the worms. The potatoes are taken up every morning for a fortnight at the critical season and the worms found upon them are destroyed. As many as a dozen worms at a time have been collected in this way at a single hop-plant.

According to Lawes and Gilbert, it is a fact that when rape-cake is applied to wheat, the wire-worms cease to eat the grain-plants and feed upon the cake. Far from the worms being killed, however, it was observed that they increased to an enormous extent when rape-cake was applied to the land. Possibly it is to this protecting influence of the cake that should be credited a considerable part of its efficacy when applied as a manure.

But in Cambridgeshire, England, rape-dust appears to have been drilled in with wheat rather freely at one time, and to have been preferred to top-dressings of nitrate of soda. Alluding to this practice, Mr. Pusey has said that, "Rape-dust drilled in with wheat appears to be most efficacious in preserving the plant on those light lands where it is apt to die off towards the end of winter."

It has been said that 8 to 16 bushels to the acre were generally found to be sufficient on wheat, to be applied either at the time of sowing the seed or by drilling it in between the rows in the spring. It was thought to be best adapted to ordinary heavy soils that are well drained or which have a dry subsoil. A. Young has reported highly favorable results that were obtained in the damp climate of Ireland by applying rape-cake early in the spring, at the rate of a ton and a quarter to the acre, to worn out grass-land. Remarkably luxuriant crops of grass were obtained. In ordinary years (in Ireland) better results were got on upland fields than on low, wet land; but in one case the effect of the fertilizer was not great when it was put upon the lands late in the spring, and a dry season followed the application.

Cotton-seed Meal.

Cotton-seed also, and the cake from cotton-seed, have been largely used in this country as manures. Indeed, considered merely as a manure, cotton-seed-cake is somewhat richer than linseed-cake. But now that methods have been devised for removing the hulls and fuzz from cotton-seed, this cake is perfectly well adapted to be used for the fattening of cattle. Properly, it must henceforth be classed among foddering materials and not as a mere manure.

From the average of many analyses of the normal product it appears that the composition of cotton-seed-meal is somewhat as follows: —

	Per Cent.
Water	8.00
Oil	13.70
Albuminous matters	44.00
Mucilaginous and saccharine matters	21.50
Woody fibre	5.70
Ash	7.10
Nitrogen, though subject to considerable variation, about	7.00
Phosphoric acid	2½–3.00
Potash	1⅓–2.00

It should be said, in parenthesis, that meal from undecorticated cotton-seed is still not infrequently met with. It is of darker color than the normal meal, from containing fragments of the black hulls, which can be detected on close inspection. Undecorticated meal contains considerably less nitrogen than the decorticated, and it is difficult to avoid the conviction that — other things being equal — it must be inferior both as a fodder and as a fertilizer, to meal from decorticated seeds. It must often happen that oil-cake prepared from undecorticated cotton-seeds will contain many coarse pieces of the hard husks and be open also to the reproach of "woolliness," and it would seem at first sight as if husks and fuzz must necessarily make the cake less easy of digestion and less safe as a cattle-food; and yet it is true that in many places at the South, the mere hulls of cotton-seeds are freely used for feeding cattle and are thought to be valuable for this purpose. It has sometimes been argued, indeed, that the cake from decorticated cotton-seeds is apt to be unduly hard, and that this objection does not apply with equal force to the undecorticated cake. But when ground to meal, as is usual in this country, the question of hardness would have no meaning. Care must be taken of course, not to feed animals upon meal or cake which has "heated" or fermented, or which is mouldy or in bad condition, and it is essential that so rich a food should be fed out with moderation. Much interest attaches to the fact that small quantities of poisonous soluble alkaloids, "cholin" and "neurin," have been detected in cotton-seed-meal, as well as in beans and other leguminous seeds. Instances are on record where calves 9 to 12 months old sickened and died when each of the animals got rather more than 3 quarts per diem of cotton-seed-meal together with skim-milk, hay, and oil-cake.

The fertilizing value of a ton of cotton-seed-meal may be computed as follows: —

140 lb. N at $0.15	$21.00
50–60 lb. P_2O_5 at $0.06	$3.00–3.60
30–40 lb. K_2O at $0.045	$1.35–1.85
Say	$25.00

By referring to the column of prices current in almost any city newspaper, it will be seen that undamaged cotton-seed-meal can often be bought, even in the Northern States, for rather less money than it is worth when considered as a mere fertilizer. And it not infrequently happens that damaged lots may be got at a considerable reduction in price, so that nitrogenous manure may be had in this form at low cost. As was said, cotton-seed-meal should by good rights be used as fodder. But so long as the generality of American farmers cannot see this very conspicuous fact, there is no reason why the stuff should not be used as a manure. The supply is large, and, so long as there is no more active demand for the material than now obtains, the price of it must continue to be low, — low enough to put even the sound meal in the category of cheap fertilizers.

Experience has shown that cotton-seed-meal is usually as good a fertilizer, as regards its nitrogen, as either dried fish or flesh-scrap, provided the land is not too dry. It is a product that should not be lost sight of by farmers who wish to buy fertilizers. A general idea, of the mode of action of cotton-seed-cake may be got from what is known of other kinds of cake. Thus, according to Lawes, "Bones either crushed or finely ground are less rapidly active than rape-cake, and, like rape-cake, they are much less so than nitrate of soda, ammonia-salts, or guano. . . When rape-cake, or other cake, is used as manure, a considerable portion of it decomposes pretty rapidly in the soil, and the more so the lighter and more porous the soil. It yields up a much larger proportion of its nitrogen and other manurial constituents in the first year of its application than does farmyard manure; and accordingly, in practice, a quantity containing one-fourth the amount of nitrogen of an ordinary dressing of dung would be applied to produce the same effect on the first crop. On the other hand, a given quantity of nitrogen applied as rape-cake would be less rapidly available and effective than the same quantity applied as nitrate of soda, sulphate of ammonia or Peruvian guano; but it would be less liable to loss by drainage, and would therefore leave a larger proportion as unexhausted residue after the first crop than either of the above-named more rapidly active manures." Analysis has in fact shown that a large proportion of the nitrogen of rape-cake is retained by the soil near the surface, and that it becomes only very gradually available for crops during a considerable length of time.

Cotton-Seed as a Fertilizer.

In the Southern States, much cotton-seed-meal is used nowadays for fertilizing sugar-cane, cotton, and corn. It is usually applied there at the rate of about 400 lb. to the acre. Formerly, the actual whole cotton-seeds were much used as a fertilizer at the South, care being taken to kill the seeds by causing them to ferment and heat, either in the soil or in compost-heaps, or simply in large piles that were kept wet. This practice was akin to the old Italian method of manuring olive and orange trees with lupine seeds that had been boiled. It is to be observed also that lupine seeds and lupine meal have occasionally been used as manure in Russia and in Germany, much in the same way that cotton-seeds are used in this country. Probably one good way of destroying the germs in such cases would be to soak the seeds in diluted sulphuric acid. This idea has been put in practice for preventing potatoes from sprouting in the spring. After the tubers have been immersed in dilute sulphuric acid long enough to destroy the germinative power of their eyes, they can be kept through the spring months without risk of suffering deterioration by sprouting.

Some farmers still maintain that for certain kinds of soils cotton-seeds are a better fertilizer that cotton-seed-meal. And M. Whitney has suggested that perhaps the oil in the seeds may exert a physical effect on the texture of the soil, i. e. it may alter the arrangement of the soil particles either by flocculation or the reverse. He finds in fact that cotton-seed-meal has a marked effect to retard the rate of flow of water through soils and that both the meal and the seeds lower the surface tension of water very considerably, whence the result that soils charged with these substances do not lift the capillary water so readily us they would if the fertilizers were absent.

Cotton-seed-meal is esteemed in some parts of this country as a manure for tobacco. In Connecticut, this crop has been grown with success by applying per acre mixtures of 1000, 1500, or 2000 lb. of cotton-seed-meal and 500, 800, 1000, or 1500 lb. of cotton-hull ashes, together with 200, 300, or 500 lb. of lime, in case the soil is not calcareous. For cotton, Prof. Stubbs of Louisiana recommends a mixture of 100 bushels of cotton-seed, 100 bushels of farmyard manure, 1 ton of superphosphate of lime and (if the land is sandy) 1000 lb. of kainit, to be applied at the rate of from 300 to 1000 lb. the acre.

Indirect Use of Oil-cake.

The composition of linseed meal is about as follows: —

	Old Process. Per Cent.	New Process. Per Cent.
Water	9.30	10.00
Oil	5.70	3.60
Albuminous matters	34.50	33.00
Mucilaginous and saccharine matters	35.40	38.40
Woody fibre	8.70	9.00
Ash	6.40	6.00

The value of this material as a fertilizer is manifest. But, as was said before, much the best way of utilizing oil-cake is to feed it out to cattle in conjunction with the rough unmerchantable fodders of the farm, and to carry to the fields the dung obtained from these cattle. On many farms in some parts of the Mississippi Valley, for example, large quantities of corn-stalks, clover haulm, and straw are produced as incidental products, which to all appearance might be fed out to advantage on those farms in conjunction with cotton-seed-meal. At all events, it could hardly be advisable, on such farms, to buy phosphates, or guano, or the other commercial fertilizers. In New England, mixtures of oil-meal and maize-meal are advantageously used as additions to the hay, ensilage, corn-stalks or other rough fodder on which milch cows are kept.

The manure produced by cattle fed with oil-cake will contain not only all the phosphoric acid and potash of the cake, but it will be rich in nitrogen also. It will contain much more nitrogen, for example, than manure obtained from cattle which have been fed upon nothing but hay. Meanwhile the oil and the albuminous and starchy or saccharine matters in the cake will be converted into fat and flesh, or milk, or some other useful product, in or upon the bodies of the animals.

It has been noticed in the experiments of Lawes and Gilbert, that nitrates are formed more slowly, and that they continue to be formed during a longer time, in soils which have been dressed with the manure of animals that have been fed with oil-cake or the like, than they are in soils that have been fertilized with ammonium salts. Oil-cake itself, or at the least rape-cake, although readily changed to nitrates in the field, does not nitrify so rapidly in laboratory experiments as many other substances. This fact may be due either to the presence of matters in the rape-cake which cripple the nitric ferment, or to the fact that the nitrogenous matters in the cake change to ammonia less rapidly than do those in some other substances. Lawes and Gilbert have found by analysis that the soils of those fields which have been repeatedly manured with rape-cake in their experiments contain larger quantities of nitrogen than any of the fields where mineral fertilizers or minerals mixed with nitrates or with ammonium salts have been used. It is said, moreover, that the fertilizing effect of oil-cake is less marked on stiff soils, which are unfavorable for nitrification, than it is on lighter land.

Pichard — on contrasting mixtures of sand and cotton-seed-meal with mixtures of sand and vegetable mould of different kinds, which contained respectively 0.3 and 0.5 % of nitrogen — found, in laboratory experiments, that the nitrogen in the cotton-seed-meal nitrified more rapidly than that in the humus.

Bran, Malt-Sprouts, Gluten-Meal and Brewers' Grains.

It may be said of each and all of these materials that they are everywhere so highly esteemed as fodders that they are seldom used directly as manures. But, like everything else, they are liable to suffer damage, and may then be usefully employed as fertilizers. The composition of bran may be estimated to be water 13 %, ash 5.5 %, nitrogen 2.3 %, potash 1.3 % and phosphoric acid 3 %; that of brewers' grains is water 76 %, or more, ash 1.2 %, nitrogen 0.9 %, phosphoric acid 0.5 %, and potash no more than 0.05 %. Hence in a bushel of the grains, weighing 60 lb., there will be about 0.54 lb. of nitrogen, 0.3 lb. of phosphoric acid and 0.03 lb. of potash, which could hardly be worth altogether as much as ten cents. Ordinarily, brewers' grains are sold at a higher price than this sum in American cities on the seaboard, though occasionally the price falls as low as 8 or 10 cents. It will be noticed however, that on farms where brewers' grains are used for feeding cows, the manure obtained from them may compensate for a considerable part of their cost. It has been said by an English writer that brewers' grains, applied as such, "form an excellent top-dressing for grass-land, increasing the quantity, improving the quality, and accelerating the ripening of the crop." Gluten-meal may contain about 14 % of water, about 0.75 % of ash, and some 4 or 5 % of nitrogen.

Malt-sprouts, though properly to be regarded as fodder and usually employed as such, have not infrequently been used directly as a manure. Analysis shows that they are well suited for this purpose, for they contain about 4 % of nitrogen, 2 % of potash, and 1.3 % of phosphoric acid. Ordinarily, they contain from 5 to 10 % of moisture and about 6 % of ashes. They were esteemed in England, at the close of the last century, as a good dressing for green wheat, being sown upon it very early in the spring, as well as upon clover and sainfoin at the same season. In wet years, satisfactory results were obtained. (Banister.) German writers have commended them for potatoes, when strewn in the furrows, and they are said to do good service on sour meadows. Other accounts state that malt-dust has occasionally been used in England for top-dressing wheat, at the rate of from 30 to 50 bushels to the acre. The fact that it is a powder fit to be strewn upon the land was of importance at a time when few fertilizing materials could be obtained in this condition. It was regarded as a forcing manure well fitted to encourage the growth of grass on weak spots in hay-fields and for pushing forward young grain which had suffered during the winter.

The marc of grapes, i. e. the residue left in the wine-press, was found by Boussingault and Payen to contain 48 % of water and 1.7 % of nitrogen.

Wool.

Woollen rags, and powdered wool in the form of flocks, shoddy, rag-wool, and the like, have a certain not very well-defined value as manure. Early in this century, Townsend proved, by pot experiments with sand and with clay, that woollen rags greatly promoted the growth of wheat and of cabbages. He remarked that in England such rags have been found of great utility as a manure, more especially for wheat. It is a matter of practical experience, he said, that, when spread at the rate of 4 or 5 cwt. to the acre, they nearly double the crop of wheat the first year, and yield a visible increase in the two succeeding years. In Oxfordshire, they were chiefly applied to wheat and tares on light gravels, but their tendency to produce blight when used too often finally rendered them unpopular. They were esteemed to be valuable also for barley and oats, and they were used extensively on hop-fields. In 1842, Hannam reported that 20,000 tons of rags are said to be used annually by the farmers of Kent, Sussex, Oxford and Berkshire. The price is about £5 the ton. They answer extremely well for hops and wheat. They are usually cut by a chopper into shreds, and applied by hand at a rate of half a ton to the acre. According to Pusey, 6 or 7 cwt. to the acre would be a fair dressing for wheat upon light land. They were seldom used, he says, on heavy land.

During a very long period rags were freely used in Central and Southern France, and in Italy also, particularly for manuring grapevines and olive and mulberry trees. It was argued that, because of their slow decomposition, rags and other analogous organic matters are well suited for fertilizing grapevines, since — unlike the more active fertilizers — they are not apt to occasion any undue development of leaves and twigs, to the detriment of the fruit and to the quality of the wine. It is said that rags are still used for manuring vineyards in the south of France, and that the price of rags fluctuates in some localities with the price of wine.

Nessler, in Baden, writing in 1893, says that the best use to be made of wool-dust is to compost it with earth and to strew the mixture in the spring in trenches between the rows of grapevines. But in England and America nowadays woollen rags command so high a price from the manufacturers of cloth that they have been put out of the farmer's reach. Generally speaking, he can only afford to use some of the refuse matters which are left after the better portions of the rags have been separated for sale to the cloth-maker. The present plan is to tear the rags to shreds, which are mixed and carded with fresh wool or with cotton, and finally spun and woven into the form of cloth, or the cotton in the rags is removed by chemical agents and the wool thus obtained is used for making felt and for various other purposes. One plan is to make horse-blankets by pricking the revivified wool into a strong jute-cloth and then shrinking and fulling this wool until the cloth has become firm and hard and warm. Flocks also, which is a trade name for the dust of wool, are made into cloth; or rather, the wool-dust is incorporated into loosely woven woollen cloth by a process of fulling or shrinking, in such wise that the interstices are filled up, and the cloth made close and smooth and heavy, while it becomes much warmer than it was before, because less open for the passage of air.

Woollen rags were formerly of much better quality than they are nowadays, because they were then free from the enormous adulteration with cotton which now prevails among all kinds of woollen goods. When the older writers on agriculture make reference to woollen rags, they mean rags which were really composed of wool, that contained some 17 or 18 % of nitrogen, whereas it might now be difficult to find such rags anywhere. As met with to-day, the rags may contain some 10 to 12 % of nitrogen, or 200 to 240 lb. of nitrogen to the ton; and if it were true that this nitrogen was directly assimilable by plants, or readily convertible into ammonia or nitrates, — in other words, if it were true that rags were a quick-acting manure, like guano, — they might still be worthy the farmer's attention, even when sold at tolerably high prices. But rags are not by any means so quick acting as guano. All kinds of wool-waste decompose but slowly in the soil, and it was on this account that a rule was laid down formerly that rags should be applied at least six months before the sowing of the crop they were meant to benefit.

The more finely divided the material, the more readily will it decompose in the soil, and the more evenly can it be distributed. Hence, if the amount of nitrogen contained in the materials were the same, shoddy or shredded wool would be better for the farmer than rags; and flocks, which are rags ground to fine powder, would be better still. Probably the nitrogen in rags would be worth to the farmer about 10 cents the pound. Hence a ton of rags that contained 10 % of nitrogen would be worth $20; or, stated in simpler terms, woollen rags are worth about a cent a pound for fertilizing purposes. More than 100 years ago, Marshall, writing of the hop-gardens in the County Kent, said, "woolen-rags are brought, by water, from London, in large netted bundles. They are sold by weight. The price, in 1790, was about five pounds sterling a ton."

Wool Acts Slowly.

It has been sufficiently proved by European experience that woollen rags have real merit as manure, in spite of their slowness of action. It is to be presumed that they would do better in warm than in cold climates, and on light and porous soils, that are not too dry, than upon stiff heavy soils. The very fact that in field practice rags sometimes did little good, while in other cases they acted as a powerful manure, goes to show that they must have fermented more or less readily, according to the character and condition of the land on which they were placed. When used by themselves in England and France, they decayed so slowly that their influence was sometimes felt during 7 or 8 years. It was held to be better, therefore, to mix them with some easily putrescible substance, like urine or guano, which should act as a ferment as regards the wool, i. e. which, while undergoing decomposition itself, should cause the wool with which it is in contact to putrefy and decompose. Some years ago, Voelcker mentioned the occurrence of samples of "shoddy" (?), with 3 to 5 % of nitrogen, that contained some 20 to 25 % of grease which hindered air and moisture from gaining access to the wool hairs and for a long time retarded their decomposition in the soil. In France considerable advantage is said to have been derived formerly from rags thus used in conjunction with liquid manures. Probably it would be better to compost rags with dung even, than to apply them directly to the land.

An experiment by Pusey upon mangolds, as set forth in the following table, well illustrates the merit of woollen rags, when the land is in such condition that the fermentation of the rags is favored: —

Manure to the Acre.	Tons of Cleaned Beet-roots, per Acre.
26 loads of farm manure	28.5
13 ditto	27.5

Manure to the Acre.	Tons of Cleaned Beet-roots, per Acre
13 loads and 7 cwt. of rags	36.0
13 ditto and 3 cwt. of guano	36.0
13 ditto and 7 cwt. of rape-cake	27.0
13 ditto and 14 bushels of bone-meal	26.0
7 cwt. of rape-cake	20.5
14 bushels of bone-meal	20.0
3 cwt. of guano	20.5
No manure	15.5

It is noteworthy how little good was done by the double dose of farmyard manure and that neither rape-cake nor bone-meal, when used in conjunction with dung, produced any useful effect. It is known, however, from the results of other experimenters, that root-crops and particularly beets often succeed well when dressed with manures which, like woollen rags, are rich in organic matter.

Wool-Waste.

"Wool-waste" which contains some 14 % of water and from 2 to 7 % of nitrogen, or about 3¾ % on the average, is still used in France and Belgium. It is said to be ploughed under in autumn at the rate of 1,500 to 2,200 lb. to the acre. Wolff has given the average composition of wool-waste as 5.2 % nitrogen and 1.3 % phosphoric acid, and Heiden cites several instances where 7 % of nitrogen were noted. The average of 30 analyses of wool-waste made at Dahme in the course of 6 years, gave 4 % nitrogen and 0.6 % phosphoric acid. Only 5 of the samples contained more than 6 % of nitrogen, and one sample contained less than one per cent.

In England, wool-waste has been used with success upon wheat on light land at the rate of half a ton to the acre; and it has been found beneficial for grass also. Sometimes this waste is used as an absorbent for the liquid excrements of men or animals. An analysis of materials taken from a vault where wool-waste had thus been used showed 27 % of water, 2 % of organic nitrogen, 1 % of ammonia, 1⅓ % of phosphoric acid, 1.1 % of potash, and 7⅓ % of lime. A sample of Belgian wool-waste that had been baked in a retort to concentrate it, and make it friable and easy of application, contained rather more than 4 % of organic nitrogen, 1 % of nitrogen in the form of ammonia, and 11 % of water.

In an experiment by Voelcker, where wool-waste was used for top-dressing wheat on a calcareous clay soil, no visible effect was produced by it for a long time; but finally the appearance of the crop improved, and though it never acquired such a deep green color as the crops grown on plots top-dressed with nitrate of soda and ammonium salts, yet the yield of grain was at the rate of 39 bushels to the acre against 31 with manure, and 40, 44 and 45 with guano, sulphate of ammonia and nitrate of soda, respectively. In this country, some farmers have found it profitable to prepare composts by fermenting wool-waste together with peat.

Petermann's analysis of a muddy material which separates from the water in which wool is scoured, and which contains the mechanical impurities that have been removed from the wool, showed 49 % water, ½ % nitrogen, ¼ % potash, and ⅛ % phosphoric acid. His analysis of "wool poudrette," which is an extremely fine powder that separates during the beating of wool, gave 9 % water, 3 % nitrogen, 0.85 % phosphoric acid and 0.67 % potash.

Steamed Wool-waste.

In Belgium and France wool-waste is often subjected to steam, under pressure, in order to concentrate and enliven it and to obtain a homogeneous friable product that can readily be applied to the land. When heated by steam, the waste melts to a liquid which yields, on evaporation, a dark brown, somewhat hygroscopic powder, with an odor like that of caramel and well nigh completely soluble in water. In Belgium this product is sold as a fertilizer under the name of "dissolved wool." It may contain from 9 to 11 % of total nitrogen and as much as 2.5 % of nitrogen in the form of ammonia. Nearly the whole of the nitrogen in the steamed waste is soluble in water. Some of it occurs doubtless in the form of leucin and tyrosin and of analogous compounds.

It was to be presumed from the foregoing facts that the steamed waste must have considerable fertilizing power, and the experiments of Petermann have proved that this is actually the case. His trials were made both in pots and in the field, and he contrasted the steamed waste both with crude wool-waste and with nitrate of soda, equal weights of nitrogen being applied in each instance. The soil was a good sandy clay-loam, and the crops were spring wheat and sugar-beets. On some of the plots and in some of the pots precipitated diphosphate of lime was mixed with the earth, but in other cases none of the phosphate was applied. In the following tables the yield of wheat is given in grams, as from 4000 grms. of soil, and that of beets is given in kilos., as from a hectare of land: —

Spring Wheat.	No Phosphate.		With Phosphate.	
	Grain.	Total Crop.	Grain.	Total Crop.
No manure	14.79	58.82	. . .	. . .
Wool-waste	17.26	62.18	17.59	63.33
Steamed waste	18.41	67.55	19.81	69.48
Nitrate of soda	20.39	73.33	20.45	70.73

Beets.	Roots.	Increase.
No nitrogen	28,573	. . .
Wool-waste	31,744	3,171
Steamed waste	37,408	8,835
Nitrate of soda	42,204	13,631

It is evident that the steamed waste did good service both upon the wheat and the beets, and that it is a better fertilizer than crude wool-waste, though decidedly inferior to nitrate of soda.

The question arose, whether the solubility of the nitrogen compounds in the steamed waste might not lead to a rapid loss of this nitrogen in the water that drains out from land to which it has been applied? But analyses of the drain-waters showed that hardly any more nitrogen went to waste from the soil dressed with steamed waste than from that to which no manure had been applied.

According to S. W. Johnson some animal matters which yield glue, such as bone, tendons, cartilage, hide and the various intestinal membranes, are rendered less soluble and less digestible by cooking or steaming, while others, such as wool, hair, horn and hoof, are made more soluble by such treatment. The glue produced by the action of hot water or steam on the substances first named impregnates the undissolved matter so that on drying the pores of materials are filled, and the porosity of the mass is so nearly destroyed that it ferments and decays but slowly.

Methods of Decomposing Woollen Rags.

Mention has already been made under leather of Runge's method of decomposing rags by means of alkalies, i. e. by boiling the woolly materials with sulphate of soda and quicklime. His process was as follows: 3 lb. of quicklime, 1 lb. of sulphate of soda, and 96 lb. of water were used for every 8 lb. of the rags, and the mixture was boiled during 3 or 4 hours. In the factory, where the operation was conducted in a boiler under an extra pressure of ½ to 1 atmosphere, the decomposition of the rags was more rapid.

Manifestly an analogous process might be employed by farmers here in New England, which would consist in simply boiling woollen rags, refuse from woollen mills, waste hair from tanneries (or bones, hoofs, and horns), in a weak solution of potashes, or in a lye obtained by leaching wood-ashes, though as a matter of course some ammonia would be evolved and lost when wool is boiled with an alkali.

Maercker has proposed that powdered rags and wool-waste should be decomposed by mixing them intimately with slacked lime, in the form of a fine powder. He uses 10 or 12 lb. of the lime for every 100 lb. of wool-dust. If need be, some moist earth may be added during the mixing. The mixture is made into a heap half a foot or so high and thoroughly moistened with water. Another layer, of equal height with the first, is thrown upon it and similarly moistened, and so on until the heap has risen to a convenient height, when it is covered with earth and left to ferment during 2 or 3 months of summer weather. Its contents will then be found to be thoroughly decomposed and in fit condition to be put upon the land. It is essential, however, that the heap should be kept moist in order that the lime may act both upon the grease and the fibre of the wool; for dry lime has little or no action upon these substances.

Hoffmann proposed some years since to boil wool or the like in caustic lye, obtained by leaching wood-ashes through lime, and to add milk of lime to the "soup." The lime would unite with the dissolved wool to form a jelly from which the revivified potassic lye could be poured off and used again and again for dissolving new portions of wool. In this way a comparatively small quantity of potash lye could be made to dissolve much wool refuse, and convert it to a fertilizer.

Separation of Wool from Cotton.

A process patented in Europe some years since for decomposing woollen rags and hair, and for separating them from cotton or linen paper stock, consisted in boiling 100 lb. of the rags for an hour in weak milk of lime, prepared from 10 lb. of quicklime and 600 lb. of water, and then beating out the disorganized wool from the cotton or linen. Another process worth mentioning was proposed in England some years ago by Ward. In order to save the paper-stock in rags of mixed composition (wool and cotton, or silk and cotton), and the seams cut from woollen rags, i. e. seams which had been sewed with cotton or linen thread, the material was exposed to steam of from 3 to 5 atmospheres pressure during 2 or 3 hours; the wool in the rags was thus converted into a friable substance, which was easily beaten out from the unchanged cotton, and collected in the form of dust. The cotton was used for making paper, while the wool dust contained some 12 % of nitrogen, and was said to be a manure of much quicker action than flocks, though less quick than guano.

It is of interest to note however, that with the cheapening of the production of cotton in recent years, and the greatly extended use of wood-pulp for paper-making, the wool in woollen rags has become relatively so much more valuable than the vegetable fibres therein that it has become customary to treat woollen rags with muriatic acid gas for the purpose of softening and disaggregating the vegetable fibres with which the material has been adulterated, so that this extraneous matter can be removed cheaply while the wool is left uninjured and fit to be used for making felt and other merchantable articles.

Several Belgian samples of woollen rags that had been disaggregated by exposure to steam under pressure, as analyzed by Petermann, showed from 7 to 8.5 % of organic nitrogen, from 0.75 to 1 % of nitrogen in the form of ammonia, and from 9 to 11 % of water.

Another method, probably much less commendable than the use of alkalies, has been proposed by Zabel in Germany for utilizing the worn-out cloths in which beet-pulp has been pressed in the sugar-houses. He draws the cloths through pan sulphuric acid and packs them tightly together in a high heap in order to promote chemical action. Beneath this heap a quantity of waste bone-black is placed, to catch the drippings of sulphuric acid, and the heap is covered also with the spent black to the depth of a foot or more. After a few weeks the cloths were found to be completely destroyed. Possibly some such process as this might occasionally be found useful by gardeners for reducing twigs, weeds, and other rubbish to a manageable manure, though probably potashes would serve still better for this purpose than sulphuric acid.

According to Maercker, a rapid and convenient way of decomposing wool-dust is to put a quantity of sulphuric acid of 50° in a lead-lined tank, and, while stirring the acid constantly, to throw into it the wool-waste until the mixture has become so thick and sticky that it can no longer be stirred. A considerable amount of heat is developed by the action of the acid on the wool, but it does no harm, and it is said that no loss of ammonia occurs.

Analyses of Hair, etc.

Payen and Boussingault found 13¾ % of nitrogen in flocks of cow-hair that contained 9 % of moisture, and Way found 11.83 % of nitrogen in refuse horse-hair that left nearly 5 % of ashes on being burned. The Münster experiment station reports, in ten samples of hair, from 3⅓ to 13¼ % of nitrogen, the mean amount having been 11¼ %. Scherer reports 17 % of nitrogen in human hair dried at 250° F. S. W. Johnson found 9⅓ % of nitrogen in hair-felt.

Hoffmann found 8.7 % nitrogen in hair somewhat admixed with lime that was obtained from a tannery.

There is a waste product of offensive odor, called "scutch," that accumulates in the yards of glue-makers and skin-dressers, which consists of a mixture of hair and other animal matters, and lime. It is esteemed as a manure after it has fermented. Way found in 3 different samples of this material 0.89, 1.35, and 1.57 % of nitrogen, from 0.50 to 1.84 % of phosphate of lime, and from 30 to 33 % of carbonate of lime, beside 24 to 26 % of water and various impurities.

In feathers, Payen and Boussingault found 15⅓ % of nitrogen; and in feather-dust, which appeared to consist of sweepings from a warehouse, Way found 6¼ % of nitrogen. But feathers are peculiarly slow to decay.

Analyses of Horn-Meal.

Payen and Boussingault found nearly 15 % of nitrogen in pure horn-shavings. Way found 12½ % of nitrogen, and cites instances where horn-shavings have given heavy crops of hops. Analyses of 9 samples of horn-meal made at the Münster experiment station showed 7½ to 14¼ % of nitrogen, or in the mean 11⅓ %. Hellriegel reports that horn-meal contains some 10 to 13 % of nitrogen, and from 6 to 10 % of phosphoric acid. In sawdust from horns of the East Indian buffalo, Knierim found 13.76 % of nitrogen, 0.24 % of phosphoric acid, and 0.80 % of sand. S. W. Johnson reports in shavings and sawdust from horns of the American buffalo (bison), 14½ to 15 % of nitrogen, and no more than 0.08 to 0.15 % of phosphoric acid. Dry horn is readily powdered after having been steamed during 10 or 12 hours.

It is to be observed that the nitrogenous compound in horn (keratin) is not readily decomposable, and is not directly assimilable by plants. Hence the propriety of putting horn-meal on light, porous and warm soils, that are not too dry, in order that the nitrogen compound may change the more easily to ammonia and to nitrates.

As procurable in this country, from comb manufacturers, horn-waste occurs in the form of thin, light shavings, which are sometimes composted with horse-manure for several months before being applied to the land. Some observers have maintained that the shavings are so light and bulky that they cannot be conveniently put to use upon the farm, not even when composted as aforesaid. In England, two centuries ago, horn-shavings were thought to be a valuable application for cold, stiff land, though of little or no use on hot ground. They were applied at the rate of seven bushels to the acre sometimes as a top-dressing, though sometimes they were strewn in furrows before the plough in the autumn. (Houghton.)

Recent experiments by Aitken in Scotland, go to show that, when in the form of very fine sawdust, horn-meal may decompose easily in the soil and act as a good nitrogenous manure even for grain-crops, but that horn in the form of coarse chips or shavings decomposes extremely slowly, and is not suitable for manure (unless it has been composted). Even the meal can hardly be well suited for spring-sown grain, though it might be good for autumn grain. Field experiments should be made in this country with Indian corn to test the question in how far horn-meal and other fertilizers which contain slowly decomposable forms of organic nitrogen can serve to replace farmyard-manure for fertilizing this midsummer crop.

A German receipt directs that the fine horn be put in a pit, layer by layer, with powdery slaked lime, and that each layer be moistened with water. The horn soon becomes soft and considerably decomposed.

A sample of hoof-meal analyzed at New Haven contained 13.9 % of nitrogen.

Value of Organic Nitrogen.

The question already alluded to, what value should be allowed for the pound of nitrogen as contained in these animal and vegetable products, is one of no little complexity. Some of these substances decompose readily by way of fermentation, while others do not; and this difference of behavior does not depend on the quantity of nitrogen which the substance may contain, but upon the kind or quality of the chemical substances in the organic matters. Thus, sheep's wool and the dry matter in urine each contain some 16 or 17 % of nitrogen; but the matter in the urine consists in good part of chemical substances, such as urea and hippuric acid, which are easily soluble in water, and which change readily to ammonia when subjected to the action of appropriate ferments, while the nitrogenous components of wool are not soluble in water and are vastly more refractory than urea, i. e. they are capable of resisting with considerable force the action of the organisms which produce fermentations. But, beside these inherent differences, are the familiar facts that decompositions due to fermentation are more rapid in warm countries and in moist porous soils than in colder regions or than on stiff land, naturally making them more valuable in some localities than in others. It is said for example of certain light, open, calcareous soils in France, which are poor in humus because of the rapid destruction of this substance through oxidation, that organic nitrogen compounds are esteemed, because they nitrify gradually and thus supply food to the crops continuously under conditions where nitrate of soda or sulphate of ammonia would speedily be washed out of the land. It is not unlikely that similar results may be produced sometimes in the Southern States of our own country.

In southern Europe, in localities where but little farmyard-manure is produced, it has long been customary to use freely several of the organic nitrogen compounds, even those which are not readily decomposable. Orange-trees, for example, are there fertilized with horn-meal, rags, skin-scraps and oil-cake, as well as with leaf-mould and composts. (Gasparin.) It has been observed by Kellner, in the hot climate of Japan, that while fish-scrap and green plants and ammonium sulphate are quickly nitrified on upland soils, they do not nitrify on swamp (rice) land kept wet by way of irrigation. The fertilizing action of the organic nitrogen compounds seems to depend, on wet land, upon the formation of ammonia. It was found that applications of lime favored nitrification on the upland soils, and the formation of ammonia in the swamps. As has been said already, it is recognized by everybody that the pound of nitrogen in bone-meal is worth much less in temperate climates than the pound of nitrogen in guano, and the remark is still more emphatically true of rags. Yet again, for all ordinary purposes the nitrogen in old leather is worthless unless it be changed by distillation, or possibly by the action of chemicals, as has been suggested above. Another point to be considered is that one or another kind of organic nitrogen may be useful for certain kinds of plants and not for others. Thus, wool, horn, and rape-cake have often done good service for hops; and Lawes has shown that for turnips rape-cake properly reinforced is a better manure than sulphate of ammonia.

Generally speaking, when the term of growth of a crop is but short, as is the case with barley and spring rye, or spring wheat, not organic nitrogen, but some easily assimilable compound of this element, such as the nitrates, would be suitable, while for the hops and turnips just now mentioned, for vines and fruit trees and other plants which are to remain some time upon the land, several of the forms of organic nitrogen might do excellent service.

Price of Organic Nitrogen.

The prices at which nitrogenized organic matters are actually sold often give very little information as to their agricultural value. Several of the substances above enumerated are put to use in the arts, and their value depends of course on the utility which can be got from them outside the domain of agriculture; and even as regards fish-scrap and tankage, the price is often determined by what the manufacturers of mixed fertilizers are willing to pay for them.

As long ago as 1866, Stoeckhardt estimated the worth of the pound of nitrogen for Saxony as follows: —

		Cents.
For easily soluble or decomposable nitrogen, as in ammonium salts, nitrates, guano, dried blood, urea, etc.	about	17
For nitrogen in fine bone-meal, poudrette, etc.	"	15
In ordinary coarse bone-meal, horn-meal, oil-cake, wool-dust, etc.	"	13
In crushed bones, the dung of stall-fed cattle, horn-shavings, woollen rags, etc.	"	9

The prices now current in this country differ much less from the foregoing than might be supposed. The original Peruvian guano has ceased to be obtainable, while the nitrogen of ammonium sulphate can be had at 19 cents the lb. and that of nitrate of soda at 14 or 15 cents. The pound of nitrogen in fine bone-meal is rated at 16 cents or thereabouts, and that in coarse bone-meal at 7 cents. The pound of nitrogen in cotton-seed-meal can usually be bought for 15 cents, and that in fish-scrap can often be bought for less than 15 cents. The inferior kinds of organic nitrogen are often estimated to be worth about 7 cents a pound.

It is to be remembered, however, not only as regards the organic matters, but of other nitrogenized substances as well, that the demand for one or another of them for manufacturing purposes may have no little influence in fixing the price at which it is sold. The nitrates, for example, are largely used by manufacturers of chemicals, and they are specially subject to fluctuation, when wars prevail, because of their use in making gunpowder. Even guano has been used, in days when it was cheaper than it is now, as the raw material for the manufacture of ammonia and ammonium salts, and for preparing prussiate of potash, Prussian blue, murexid-purple, and other dyes. (Voelcker.)

Experiments with Organic Nitrogen.

Lawes has expressed the opinion that, for the climate of England, the nitrogen in shoddy, and in most other nitrogenous organic matters used as manures, is so slowly effective that, as a rule, it should be valued at only from one-half to two-thirds the price of that in nitrate of soda, sulphate of ammonia, or guano. But it is evident that climate may have a very important influence in this matter, and, in fact, experiments made in Japan, on rice, by Kellner and his pupils, show that in the presence of water in a hot climate, several forms of organic nitrogen may do excellent service as fertilizers. In the experiments, the results of which are recorded in the following table, nitrogen was applied at the rates of 41.4 and 82.8 kilos. to the hectare, in the several different fertilizers; and in addition to the nitrogen, each plot of land got 200 kilos. of phosphoric acid, and 110 kilos. of potash to the hectare, in the forms respectively of phosphate of soda and carbonate of potash. In each instance, the fertilizers were applied several days before the rice-plants were set out. The soil was naturally rich in nitrogen, containing when air-dried 0.61 % of it.

Fertilizer.	Grm. of shelled rice, increase over the unmanured plot.	Relative increase, the gain due to sulphate of ammo- being regarded as 100.
Sulphate of ammonia, in solution . . .	99.5	100
Bone-meal, steamed, with 4 % N	142.5	143
Fish-scrap, from very small fishes, 9.9 % N	134.7	135
Fish-scrap, another kind, with 9.5 % N .	133.9	134
Blood-meal, 14 % N	125.0	126
Bone-meal, from raw bones, 4.7 % N . .	119.7	120
Dried distillery slop, 2.3 % N	118.9	119
Horn-meal, 14.7 % N.	116.2	117
Peru guano, 7.6 % N.	162.5	114
Night-soil, fermented, 0.51 % N	102.8	103

Fertilizer.	Grm. of shelled rice, increase over the unmanured plot.	Relative increase, the gain due to sulphate of ammonia being regarded as 100.
Press-cake from soy beans and roasted wheat, 3.5 % N	101.8	102
Rape-cake, 5 % N	100.7	101
Farm-manure, containing some night-soil. The mixture was tolerably well rotted, and contained 1.1 % of N	94.6	95
Rice husks, 2.1 % N	54.0	54
Green plants, chiefly hard grasses, 0.5% N,	45.7	46

The following table shows what proportion of the applied nitrogen was recovered in the crops, and gives (in the last column) the relative values of the several kinds of nitrogen: —

Fertilizers.	Percentage of applied nitrogen which was recovered in the increase of crops.	Relative amounts of nitrogen recovered in crops.	Relative efficiency of the fertilizers as shown by mean gain of crops and by the amounts of nitrogen recovered.
No manure	...	..	..
Sulphate of ammonia	61%	100	100
Bone-meal, steamed	86	141	142
Fish-scrap, 9.9 % N	83	135	135
Fish-scrap, 9.5 % N	81	132	133
Blood-meal	82	134	130
Bone-meal, raw	73	120	120
Distillery slop, dried	72	117	118
Horn-meal	71	115	116
Peru guano	72	117	116
Press-cake	65	106	104
Rape-cake	68	110	106
Night-soil	66	108	106
Farm-manure	50	81	88
Rice-husks	26	42	48
Green plants	23	37	42

It is to be remembered that these particular experiments were made under conditions extremely favorable for the decomposition of organic matters, viz., in wet rice-fields in a country where the summer temperature is very high. But it is interesting to observe that the animal matters (bone-meal, fish and blood) stand at the head of the list, and that horn-meal exhibits considerable merit, while the rape-cake and the press-cake appear to have decomposed rather slowly. It is evident enough that sulphate of ammonia, night-soil and stable-manure were at a disadvantage because a part of the soluble forms of nitrogen which are contained in them were washed away in the water with which the rice-field was irrigated, while the nitrogen of the organic matters was gradually changed to ammonia, which was continually put to profit by the rice-plants.

It was noticed that the plants on the plots fertilized with green grass, rice-husks and straw — and to a certain extent the plants dressed with blood-meal — suffered somewhat at first because of the rapid decomposition of these materials, and the setting up of reducing action in the soil. With the exception of the plants on the straw-plot, which were ruined, the others recovered their vigor in the course of a month. But this experience enforces anew the lesson — long known, for that matter, — that easily decomposable organic matters should never be applied at the time of seeding or planting. They may either be worked into the soil several weeks before seeding, or else be fermented (in a compost heap), before being put upon the land.

Kellner dwells on the fact that the water on the rice-fields hindered nitrification. In these experiments, not nitrates but ammonia was formed by the decomposition of the organic manures, and this ammonia was put to use by the rice-plants; whereas in experiments on upland soils that were not irrigated, the formation of ammonia from the organic matters was quickly succeeded by nitrification in the hot summer weather, and a part of the nitrates was carried down deep into the subsoil by the abundant rains which prevail at that season in Japan. Experiments made in Germany by Seyffert upon kohl-rabi were so arranged that the plants should be well fed and subjected to like conditions, except that they got different kinds of nitrogenous food, as in the table.

When fertilized with	Grams of Crop were obtained.
No nitrogenous fertilizer	76
25 grams N in crude Mejillones guano	71
" " leather-meal (steamed)	469
" " steamed bone-meal	1,572
" " dried blood	1,654
" " horn-meal (steamed)	2,005
" " nitrate of soda	2,608

Whence it appeared that nitrate of soda and horn-meal were specially good, and leather-meal particularly bad. As regards dried blood, compare the results given on a previous page.

To control the foregoing results, Albert tried similar experiments with oats, as follows: —

Kind of Nitrogenous Fertilizer used.	There were harvested Grams of			
	Grain.	Straw.	Roots.	Total Plant.
No nitrogen	5.2	15.7	14.3	35.2
Leather-meal (steamed)	13.3	22.2	13.6	49.1
Leather-meal fermented	21.5	36.4	17.2	75.1
Steamed bone-meal	36.2	41.3	20.0	97.5
Steamed bone-meal fermented	34.0	44.3	20.3	98.6
Dried blood	24.8	44.5	18.5	87.8
Dried blood fermented	29.6	57.2	16.5	103.3
Horn-meal (steamed)	47.5	70.4	25.4	143.3
Nitrate of soda	48.9	62.6	27.9	139.4
Sulphate of ammonia	33.2	44.6	21.1	98.9

Here again nitrate of soda and horn-meal did well, and fermented blood-meal also. Leather-meal was of no account, and it served no useful purpose for the crops that succeeded the oats. Even the fermented leather-meal was of but little use.

Heinrich has concluded from his own experiments upon oats that if the fertilizing action of sulphate of ammonia be regarded as equal to 100, the effect of flesh-meal may be stated as equal to 72, that of bone-meal as 65, that of leather-meal as 59, of blood-meal, 58, and of horn-meal, 33. Saltpetre acted similarly to ammonium sulphate but was not included in the comparisons, because some of the plants were sickly. As regards the nitrate and the sulphate, it was found to be immaterial whether they were harrowed in or buried more deeply, but the effects produced by the meals of flesh, bone, leather, and blood, were very much less when they were harrowed in to the surface than when they were intimately mixed with the soil.

In the following trials by Eckenbrecher, it would seem that the nitrogen of the blood, bone and horn were applied under conditions specially favorable for the fermentation of these substances, and for the growth of plants. The experiments were made in sterile sand contained in boxes nearly a square yard in area and rather more than a foot and a half deep. Fit quantities of the ash-ingredients of plants were mixed with the sand, and each box received in addition 5 grams of nitrogen, in the form of one or another of the substances enumerated in the following list. The sand was properly watered, of course, and the temperature was favorable for the growth of plants. The experiments lasted two years. The results are set forth in the following table, which gives the weights of the crops harvested from the sand admixed with ash-ingredients, according as one or another nitrogenous fertilizer was added: —

	Oat Grain. grm.	Total Crop. Straw and Grain. grm.
No nitrogen	12.6	80
Blood-meal	42.2	225
Horn-meal	38.1	227
Bone-meal	47.7	249
Sulphate of ammonia	46.0	251
Nitrate of triethylamin	52.9	252
Nitrate of soda	58.3	260
Crude guano	15.5	92

The behavior of the guano is remarkable, but was not explained. With horn-meal and bone-meal the ripening of the grain was delayed appreciably, as had previously been noticed by Albert. The good effects of triethylamin are interesting, since this substance is obtained in considerable quantities of late years as an incidental product in the manufacture of alcohol from beet-root molasses.

The field experiments of Wagner on the relative availability of organic nitrogen were made with summer rye followed by flax, summer wheat and carrots. He obtained the results stated in the following table: —

	First year.	Average of 1st and 2d years.	Average of 1st, 2d and 3d years.
Nitrate of soda	100	100	100
Sulphate of ammonia	85	74	88
Peruvian guano	84	88	80
Blood-meal	67	67	69
Castor-pomace	62	65	67
Green-crops ploughed in	62	60	68
Horn-meal	63	61	63
Fish-guano	51	59	64
Steamed bone-meal	42	53	61
Flesh-meal	44	47	54
Wool-dust	27	28	33
Stable-manure	11	16	32
Leather-meal	13	12	20

Much Horn equals less Blood.

Pot experiments upon oats, made at New Haven by S. W. Johnson, in which blood-meal and horn-meal were contrasted, brought out the interesting fact that the crop-producing power of the nitrogen in blood and in horn is more nearly alike in proportion as the amount of nitrogen applied to the land is larger. For, since a portion of the nitrogen in horn is available, it is possible to add enough of it to supply all that a maximum crop requires;

and with each successive increase in the amount applied the production of a maximum crop is more nearly attained, while the difference in availabilty between the horn and the blood becomes smaller.

For these experiments pairs of pots were filled with loam taken from a field which had not been fertilized for many years, appropriate quantities of muriate of potash and superphosphate of lime were added, and varying amounts of the nitrogenized matters to be tested, as stated in the following table. The dried blood contained 13.40 % of nitrogen, the hoof and horn-meal 13.54 %, and the horn-shavings 15.37 %. All these nitrogenous matters were finely ground. They were the same as those tested by Johnson with pepsin solution, as stated in a subsequent table. Nitrogen was added to the pots in such quantities as would amount to 20, 40, and 60 lb. to the acre, respectively. The oats grew well, and though attacked by smut when in flower, most of the crops seemed to escape serious damage: —

Fertilizers added. Grm.	Nitrogen in Fertilizer. Grm.	Dry Crop. Grm.	Nitrogen in Crop. Grm.
None	None.	23.4	0.2042
“	“	25.1	0.2112
“	“	22.4	0.2055
“	“	22.9	0.2050
0.8508 of dried blood	0.114	29.6	0.2378
0.8508 “ “	0.114	29.7	0.2410
1.7015 “ “	0.228	32.7	0.2816
1.7015 “ “	0.228	33.3	0.3173
2.5524 “ “	0.342	41.6	0.3844
0.8419 hoof and horn	0.114	24.1	0.2056
0.8419 “ “	0.114	26.0	0.2346
1.6838 “ “	0.228	26.5	0.2411
1.6838 “ “	0.228	28.6	0.2528
2.5257 “ “	0.342	33.1	0.2886
2.5257 “ “	0.342	32.7	0.2808
0.7417 horn shavings	0.114	22.5	0.2073
0.7417 “ “	0.114	19.4	0.2457
1.4834 “ “	0.228	26.1	0.2280
1.4834 “ “	0.228	28.5	0.2534
2.2251 “ “	0.342	32.3	0.3140
2.2251 “ “	0.342	32.8	0.2870

It appeared that applications of nitrogen at the rate of 20 lb. to the acre, in the form of blood, gave four times as much increase of crop over the yield of the unmanured loam as the same amount of horn-nitrogen; that when nitrogen was applied at the rate of 40 lb. to the acre in the form of blood the increase was two and a half times as much as that got from the same amount of nitrogen in the form of horn, and that when 60 lb. of nitrogen were applied the increase of crop caused by the blood-nitrogen was only one and three-quarters as much as that caused by horn-nitrogen.

As regards the increase of nitrogen in the crop, 20 lb. of blood-nitrogen to the acre gave nearly twice as much increase as the same amount of horn-nitrogen; 40 lb. of blood-nitrogen gave two and a half times as much increase as the same quantity of horn-nitrogen; and 60 lb. of blood-nitrogen gave one and two-thirds as much increase as the same quantity of horn-nitrogen.

Johnson suggests that the very fact that blood-meal decomposes readily in the soil may perhaps put it at a disadvantage as compared with horn-meal when large quantities of the two materials are used; for it might easily happen that a large dressing of a substance so easily decomposable as blood could "burn" a growing crop while a dressing of horn-meal equally rich in nitrogen would be wholly beneficial. It will be noticed that in Johnson's experiments the horny materials proved to be decidedly inferior as fertilizers to the blood-meal. The average increase of crop brought by the horn-fertilizers as compared with the increase due to the blood was as 47.5 : 100; and the average increase of nitrogen in the crops from the use of the different materials was as 50.5 : 100. These results manifestly support the old view that the pound of blood-nitrogen should be rated at a price twice as high as the pound of horn-nitrogen. Similar experiments made with Indian corn indicated that castor-pomace at its best could be rated at 85 % when nitrate of soda equals 100 %. The nitrogen in linseed-meal was somewhat less available, and was rated at 80 %, while that of dried blood was 77 %. Cotton-seed-meal was 76 %, castor-pomace at its worst 74 %, and hoof- and horn-meal 72 %. Dried fish did less well than the oil-cakes, and was rated at 70 %, while tankage was 68 %.

One item of evidence in favor of horn-meal is that the keratin of which it consists is susceptible of putrefaction. Thus Morgen, after having moistened samples of horn-meal and leather-meal, kept them for some time under conditions favorable for putrefaction, and finally determined by analysis that 61.62% of the nitrogen in the horn-meal had gone into solution, while only 34.56 % of that in the leather-meal had dissolved.

Value of the Organic Matters as Sources of Nitrates.

Instead of determining the weights of crops harvested, as in the foregoing experiments, Muntz and Girard have sought to compare several organic fertilizers by noting the amount of nitrate which is formed in a given space of time from each of the fertilizers when they are exposed to the action of the nitrifying ferments under similar and favorable conditions. For these experiments, a weighed quantity of the fertilizer was mixed with a definite amount of loam, which was moistened and kept for several weeks at temperatures ranging from 59° to 77° F. The amount of nitrate in the loam was determined at the beginning, and from time to time during the course of the experiment. Thirty days was found to be a convenient term for the tests, for the reason that while a large proportion of the nitrogen in materials which are readily nitrifiable will be changed to nitrate in the course of a month, the nitrogen in materials which are less readily nitrified will continue to undergo change for a long while; as long, indeed, as the conditions favorable for nitrification are maintained. The general result of the trials made in this way was that the nitrogen in ammonium compounds nitrifies much more readily than that in organic matters; that the nitrogen in guano and in the dung of bats stands next in order; then that in leguminous plants which were ploughed under as green manure; and then the nitrogen in dried blood, flesh-meal, horn-meal, and roasted horn; while the nitrogen in roasted leather nitrified but slowly, and that in raw leather hardly at all. Some of the results of these experiments are given in the following table: —

Substance examined.	Nitrogen in the Substance. Per cent.	Percentage of the Nitrogen of the Substance which was changed to Nitrate. In 30 days.	In 39 days.
Ammonium sulphate . . .	20.40	75.00	83.76
Dried blood	11.92	72.44	73.56
Roasted horn, fine	13.66	71.02	73.17
Flesh-meal	11.08	70.40	66.15
Horn-meal, fine	14.06	55.50	72.16
Poudrette, coarse	2.30	18.14	14.94
Roasted leather, fine . . .	7.18	11.62	16.47
Raw leather, fine	8.05	0.39	. . .

Tests by Way of Artificial Digestion.

Another method of testing the value of the nitrogen in organic compounds has been proposed by Stutzer and Klingenberg, viz. to subject the materials to a process of "artificial digestion." That is to say, a weighed quantity of the fertilizer is left to soak for a number of hours in a warm liquid, similar to the gastric juice of animals, prepared by mixing pepsin with diluted muriatic acid. The idea on which this method of research is based is, that those fertilizers which are most readily soluble and decomposable in the stomach, or rather those which contain the largest proportion of soluble nitrogen compounds, will be likely to do the best service in the field.

Stutzer and Klingenberg obtained the following results: —

	Total Nitrogen in the Material. Per cent.	Of each 100 Parts of Nitrogen there were	
		Soluble in the Pepsin.	Insoluble in the Pepsin.
Blood-meal	13.54	89.75	10.25
Leather-meal (steamed)	6.91	39.19	60.81
Horn-meal (torrefied)	13.70	40.73	59.27
Horn-filings (crude)	7.06	23.43	76.57
Poudrette	6.77	80.23	19.77
Poudrette (from another city)	1.58	22.92	77.08
Waste wool	10.55	2.72	97.28
Bone-meal (raw)	4.02	95.45	4.55
Ditto, another sample	3.94	97.95	2.05
Bone-meal (steamed)	4.31	92.74	7.26
Ditto, another sample	2.43	88.35	11.65
Peruvian guano, from which the uric acid had been removed	11.08	94.53	5.47
Wool that had been treated with sulphuric acid	12.37	85.34	14.66

In this country, Shepard and Chazel, and S. W. Johnson,[1] have tested a variety of products by means of the pepsin process, with the following results: —

SHEPARD AND CHAZEL'S TESTS.

	Total Percentage of Nitrogen in the Material.	Of each 100 Parts of Nitrogen there were	
		Soluble in the Pepsin.	Insoluble in the Pepsin.
Dried blood, red	15.19	99.81	0.19
Dried blood, black	14.49	78.61	21.39
Dried fish-scrap	11.56	88.67	11.33
Dried slaughter-house refuse	12.84	61.29	38.71
Dried flesh-scrap (excellent)	14.17	93.32	6.68
Dried king crab (shell and all)	12.15	52.10	47.90
Acidulated fish-scrap	7.14	84.59	15.41
Roasted leather-meal	9.92	37.80	62.20

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[1] Report of Connecticut Agricultural Experiment Station, 1885, page 117.

	Total Percentage of Nitrogen in the Material.	Of each 100 Parts of Nitrogen there were	
		Soluble in the Pepsin.	Insoluble in the Pepsin.
Cotton-seed-meal	7.76	83.18	16.82
Cotton-seed-meal (from which all oil had been removed)	8.56	85.67	14.33
Cotton-seed (ground)	4.23	83.10	16.90
JOHNSON'S TESTS.			
Kiln-dried blood, black	13.44	96.8	3.2
Kiln-dried blood, black	13.47	97.9	2.1
Fish-scrap (menhaden)	10.64	85.9	14.1
Fish-scrap, dried and ground	8.76	71.2	28.8
Dried horse-flesh	8.12	61.3	38.7
Ground bone (clean, hard, and dry)	4.11	98.8	1.2
Cotton-seed-meal	6.68	92.7	7.3
Castor pomace	6.88	92.4	7.6
Maize-refuse after extraction of starch	5.55	82.9	17.1
Buffalo-horn sawdust	14.85	7.2	92.8
Horn-waste (shavings)	15.37	22.4	77.6
Fine ground hoof and horn	13.69	28.2	71.7
Wool-waste	11.25	4.8	95.2
Felt-waste	13.12	7.2	92.8
Leather, fine and brittle	8.13	25.4	74.6
Leather treated by benzine process	8.40	35.9	64.1
Leather reduced by superheated steam and ground	6.85	33.3	66.7
Hair and leather mixture	6.91	13.8	86.2

In general, the foregoing results consist fairly well with what is known of the behavior of the several kinds of fertilizers in the field, though those which relate to horn-meal do not well agree with some of the results of pot-experiments as given on a previous page.

Blood and bone-meal, flesh, oil-cake, and unsophisticated fish-scrap, commend themselves here as they have done in farm practice; leather-meal and wool-waste exhibit their well-known inertness; while dried slaughter-house refuse and over-dried fish-scrap occupy a middle place. As Professor Johnson has remarked, this process of analysis does divide the organic compounds into two classes, according to the solubility of their nitrogen. In one class more than half the nitrogen is soluble, while in the other scarcely more than a third of the nitrogen is soluble. But to this first class belong all the compounds which farm experience has shown to be generally and really useful as fertilizers.

One noteworthy item in this list of experiments is the observation that leather-meal which has been soaked in so weak an alkali as a solution of borax becomes tolerably easily soluble in the pepsin solution. A sample of leather reduced by superheated steam gave up 84 % of its nitrogen to pepsin solution after treatment with borax, while only 33⅓ % of the nitrogen was soluble before the borax treatment.

Distillation of Rags, etc.

A device for utilizing the comparatively inert nitrogen of rags, which was practised in a small way in Germany some years since, is worth mentioning as a matter of history. Indeed, it has recently been described anew as a method of practical merit. The rags were distilled upon the farm, and the ammoniacal fumes were collected in acid or in water. The liquid was then mixed with earth, and applied to the land. The distillation was effected in a simple chimney, about 6 feet high by 2 feet wide, built roughly of bricks. At the bottom of the chimney was an opening for the removal of ashes and the admission of air. At the top the chimney could be closed by a movable plate; and at a point below the top a knee-shaped tube led from the chimney to a series of wooden vessels charged with water or diluted sulphuric acid, and connected with one another by means of wooden tubes.

To start the apparatus, a fire of wood was built in the chimney, and the latter was then filled with rags and closed at the top. Air enough was admitted at the bottom of the chimney to permit the lowest rags to burn slowly, or rather to glimmer or smoulder away, and so heat the rags next above them. There was thus always, from first to last, one layer of the rags exposed to a temperature high enough to effect distillation, just above the layer of rags which were actually burning. The fumes from the smouldering rags passed over through the abduction flue into the absorbing vessels.

The apparatus was of extreme simplicity and cheapness, such as any man could construct for himself. The ashes drawn from the bottom of the chimney were mixed with earth, and were used in conjunction with the ammoniated liquor, and the whole formed an excellent manure as quick acting as guano.

It is manifest that any such operation as this would be possible only in countries where labor is cheap, or upon farms where there might happen to be occasionally labor unfit for more remunerative undertakings. It is not improbable, however, that this method might be used sometimes with advantage by small proprietors in this country for obtaining an active fertilizer from mixtures of peat and old leather, or occasionally perhaps for burning weeds, or other refuse raked up from gardens. The process is interesting from its resemblance to that by which the ammonium salts of commerce are obtained from coal; and, as has been said, coal teaches, even more emphatically than leather, that the nitrogen in organic compounds is not always immediately available as a source of plant-food. What is true of coal in this sense is true also in some degree of peat, and of vegetable mould, the black earth of ordinary soils.

Inert Nitrogen of the Soil.

As has been said already, it is a fact of deep importance that much of the nitrogen in ordinary soils exists there in an inert and comparatively useless state, somewhat analogous to that in which it exists in leather or in coal.

Not only the nitrogenized portions of plants and of dung, but even ammonia itself, appear to be changed in part in the soil to humus-like substances, many of which seem to be incapable of supplying nitrogen directly to the higher orders of plants, though others change more or less readily to ammonia and to nitrates and so become gradually available for crops.

The humus of the soil is never devoid of nitrogen; that in the good loams of Old and New England may contain 4 or 5 % of this element, while in the humus of the arid soils of California, Hilgard has found almost 16 % of nitrogen, on the average. Air-dried peat sometimes contains as much as 3 %of nitrogen. Lawes and Gilbert have estimated that the ordinary arable soil at Rothamsted contains about 3,000 lb. of nitrogen per acre in the first 9 inches of depth, about 1,700 lb. in the second 9 inches, and about 1,500 lb. in the third 9 inches, i. e. about 6,200 lb. per acre to the depth of 27 inches. They have observed furthermore that a sample of Oxford clay (calcareous) brought up from a depth of between 500 and 600 feet contained approximately the same percentage of nitrogen, 0.04 %, as the Rothamsted subsoil at a depth of 4 feet. They remark that there are probably very few sedimentary rocks which do not contain an appreciable amount of nitrogenous organic matter.

It was at one time thought by some chemists, notably by Mulder, that this nitrogen of the soil is in the form of humate of ammonia, — it being further assumed that the humate in question is not readily decomposable by alkalies, and the other agents that destroy ordinary ammonium salts. But this view is highly improbable. It is true, indeed, that a part of the nitrogen compounds of the soil are slowly decomposed, with evolution of some ammonia, when brought into contact with lime or the caustic alkalies, and especially when heated with these agents; but, on the other hand, they are only slightly decomposed by the weaker alkali magnesia, though magnesia is well known to be fully competent to decompose ammonium salts.

The probabilities are decidedly in favor of the view previously expressed, that whatever humate of ammonia may be formed temporarily in the soil by the absorption and fixation of any carbonate of ammonia, formed there by the decay of plants or manures, must soon change to the condition of an inert nitrogenized compound of another order, which contains no true ammonia.

The fact that some kinds of peat exhale ammonia in burning, or even in putrefying, is no evidence that the peat contains ammonia ready formed, any more than the evolution of ammonia from flesh, bones, rags, coal, and many other nitrogenized substances, under like conditions, is evidence that they contain ammonia.

Amids in Soils.

There are good reasons for believing that much of the soil-nitrogen is contained in compounds belonging to the class of amids. Urea, for example, is an amid of carbonyl, —

$$CH_4N_2O = N_2\left\{\begin{array}{l}CO''\\ H_2\\ H_2\end{array}\right.$$

and acetamid is an amid of acetyl,

$$C_2H_5NO = N\left\{\begin{array}{l}C_2H_3O\\ H_2\end{array}\right.$$

It is known that amids, such as leucin ($C_6H_{13}NO_2$) and tyrosin ($C_9H_{11}NO_3$), occur habitually among the products of the decay of albumen and allied substances, and it is not improbable that these particular amids, and others analogous to them, though still more difficultly soluble, are formed in the soil when albuminous substances, i. e. plants and manures, decay there.

In favor of this view is the fact just stated, that a part of the humus of the soil slowly decomposes when boiled with strong alkalies, while ammonia is set free, much in the same way that the true amids are slowly decomposed with evolution of ammonia when thus treated with alkalies. Indeed it may be said in general, as Berthelot has insisted, that the nitrogenous matters in soils not only give off some ammonia when they are boiled in alkaline solutions, as many well known amids do, but that — as is the case also with true amids — small amounts of ammonia may be obtained from them by boiling continously in acids or even in pure water. On thus boiling the soil-compounds with an acid, it is noticed that a certain proportion of the nitrogen compounds become soluble.

But little Ammonia in Soils.

It is on account of this evolution of ammonia, when loams are boiled with milk of lime, that the old statements given in the books as to the amount of ammonia in soils can no longer be accepted as strictly true. As regards the setting free of ammonia when nitrogenous matters are heated with alkalies, it is to be observed that much depends on the degree of concentration of the alkaline liquor, as well as upon the character of the substance on which it is made to act, and upon the temperature of the liquid. In many cases, considerable quantities of ammonia may be liberated at temperatures much below that at which water boils. Not infrequently, indeed, a considerable evolution of ammonia can be detected at temperatures not much higher than 100° F.; sometimes it is evident enough even at the ordinary temperature of the air.

It is important, no doubt, to know the fact that there are substances in the soil, through the decomposition of which ammonia can readily be obtained, and it is well to gain an idea as to about how much of the easily decomposable substances may be contained in a given sample of earth. The error was in counting the easily decomposable matters as if they were really ammonium compounds. From the results of some of these old experiments it seemed to appear that as much as 0.10 % of ammonia might be contained in soils such as the more accurate experiments of to-day show to contain no more than 0.001 or 0.002 %.

It was not until Boussingault substituted magnesia for the stronger alkalies in the analytical process of estimating ammonia, that any useful results were obtained, and even the magnesia process has been improved upon latterly. Many absurd hypotheses have been advanced on the strength of the old belief, that the nitrogen in the soil is in the form of ammonia, though it is not strange that the misconception should have arisen, for as Boussingault has observed, the mere admixture of caustic lime with a good garden soil at the ordinary temperature is sufficient slowly to set free ammonia through the decomposition of the nitrogenized humus.

Disputes as to the Comparative Merit of Nitrogen and Ash-Ingredients in Manures.

It was because of this old error that disputes arose formerly as to whether there was any use in applying nitrogenous fertilizers like ammonium sulphate or nitrates to the land. The argument was that there is plenty of ammonia in the soil already, and that consequently only ash-ingredients such as phosphates or potash or lime need to be applied to the soil in order to increase its natural fertility. Some chemists even went so far as to argue that the good effects of guano are due solely to the phosphate of lime and the potash that are contained in it. The absurdity of all such statements was shown very emphatically by some of the earliest experiments of Lawes and Gilbert, as will appear from the following table: —

From an acre of land, manured with	There was harvested	
	Bushels of Grain.	Lb. of Straw.
14 tons farmyard-dung	22.00	1476
Ash of 14 tons farmyard-dung	16.00	1104
Nothing	16.75	1120
700 lb. bone-ash superphosphate	16.75	1116
635 lb. of the superphosphate and 65 lb. sulphate of ammonia	21.25	1368

It is now known by every one that the supposition that ash-ingredients alone are a sufficient manure, was fundamentally wrong. In spite of the fact that there is usually a great deal of nitrogen in the soil, it is seldom, in cold countries, that any large proportion of it is in a condition fit to be immediately assimilated by plants. Much of the soil-nitrogen does, of course, continually undergo change in summer weather, with formation of nitrates upon which crops can feed, though it is to be noted that in most cases the nitrogen in the soil nitrifies more slowly than that in those kinds of fertilizers, containing organic nitrogen, which are most highly esteemed by practical men. It is the business of the farmer sometimes to render the soil-nitrogen assimilable to crops, and at other times to supplement it with supplies of active nitrogen brought from the farmyard or from abroad; and either the one or the other of these acts may be the more judicious according to circumstances.

The Soil-nitrogen Nitrifies.

In hot countries, especially, and whenever the conditions are favorable for nitrifying the soil-nitrogen, it can be readily put to profit by many kinds of crops, notably by Indian corn; though harm may sometimes be done by it to some crops, as when the supplies of easily assimilable nitrogen are excessive. Thus it was pointed out by Mr. Russell many years ago, that the hot summer climate of the United States practically restricts the cultivation of winter wheat to soils which would be regarded as second-class wheat-land in England and Scotland, for when sown here on rich loamy soils, winter wheat is apt to grow rank and to suffer from rust and mildew, while it may succeed well on light gravelly loams rather deficient in vegetable matter, and of no more than moderate fertility, such as would be little productive of wheat in Great Britain. So, too, in respect to tobacco, when planted on rich clay loams, the leaves are apt to grow coarse and to be deficient in aromatic qualities; hence a tendency nowadays to restrict the cultivation of this crop to light, sandy loams, which are found to be best suited for producing tobacco of fine quality.

As has been said already, some small part of the inert nitrogen of the soil may perhaps be derived occasionally from the reduction of ammonium salts and nitrates; but it is none the less true that most of it comes directly from albuminoids and other compounds of nitrogen which formed a part of plants and animals that have decayed in or upon the soil. When vegetable matters, or the remains of animals, or dung, undergo change in the earth, a part of the nitrogen which is contained in them is converted into ammonium salts and nitrates, a small part may, under exceptional circumstances, escape into the air as free nitrogen gas, and the remainder is left in the soil in the form of the organic compounds now under discussion, most of which are insoluble in water, and, comparatively speaking, inalterable when exposed to water and air.

The Hydrogen and Carbon in Organic Matters waste away faster than their Nitrogen does.

It often happens that micro-organisms in the soil act to destroy the carbon and the hydrogen in humus rather than the nitrogen, so that, after the first hot fermentation of decaying vegetable matters has ceased, the waste of hydrogen and carbon may be much more pronounced than the loss of nitrogen, and the humus produced may contain a considerably larger proportion of nitrogen than the substances from which it has been formed. This fact has been noticed by several different observers, and is seen very conspicuously in the peculiar "black earth" of Russia, which may contain, when dry, according to Kotstytcheff, as much as 4, or 5, or 6 % of nitrogen, while there is no more than 1 or 2 % of nitrogen in the plants from which this humus has been formed. Still more extraordinary is the extremely high proportion of nitrogen (16 %) in the humus of the arid soils of California. It is evident that, under the conditions of decay to which vegetable matters are there subjected, the carbohydrates which these matters contain are oxidized more rapidly than the nitrogenous constituents, and that nitrogen accumulates in the residual humus until this substance may come to contain, in some instances, a higher percentage of nitrogen than is contained in albumen itself. (Hilgard and Jaffa.)

According to Loges, a certain part of the inert nitrogenous matter in humus is soluble in muriatic acid, and appears to play the part of a weak base. He finds, at all events, on leaching loams with the acid and evaporating to dryness the liquid thus obtained, that a nitrogenous black residue is left, even when soils are operated upon which contain but little humus. It is evident that this black residue must be a substance of different chemical character from the humic acids, since these bodies are very little soluble in muriatic acid, and only dissolve therein to the extent of faint traces. Analysis showed that a sandy soil, rich in humus, contained 0.804 % of nitrogen, and that 0.322 % of nitrogen was dissolved out of the soil by muriatic acid. In another instance, the acid dissolved 0.083 % of nitrogen from a loam that contained 0.367 %.

Berthelot, in his turn, has noticed the formation in the soil of certain volatile nitrogenous compounds which he regards as ptomaines that have resulted from the activity of micro-organisms. Under fit conditions, these compounds seem to be produced more abundantly than ammonia.

Crops use much Soil-Nitrogen.

From what has been said, it follows as a matter of course that the amount of nitrogen in a soil, as determined by analysis, is no fair test of the power of that soil to produce crops.

On the other hand, the addition to certain crops of a few pounds of nitrogen per acre, in the form of guano or of nitrate of soda, will often produce effects which are out of all proportion greater than could be produced by so small a quantity of nitrogen if it were placed upon a soil wholly devoid of that element. A good example of this forcing power of the easily assimilable nitrogen compounds is seen when nitrate of soda is applied to winter wheat in the spring, i. e. at a season when the ground is still somewhat cold, and nitrification has not yet become active.

There is much evidence, withal, tending to show that one merit of superphosphates and of precipitated phosphate of lime may be due to the fact that soils charged with these fertilizers are thereby made fit for the residence and support of certain micro-organisms which have power to convert the nitrogen of humus into compounds that can be assimilated by crops. A somewhat similar remark will apply to potassic fertilizers also, particularly to wood-ashes, and to mixtures of superphosphate and a potash salt. For example, Voelcker applied to land seeded with clover and Italian ray-grass, a mixture of plain superphosphate, made from rock, and muriate of potash, at the rate of 4 cwt. of each to the acre; and observed that the effect produced on the clover-plant was truly magical. The clover grew remarkably strong, and the ray-grass was vigorous also, and very heavy crops of grass were obtained—some 15 tons to the acre. As compared with the product from unmanured land, the mixed fertilizers gave an increase of 9,400 lb. grass to the acre, though the superphosphate used by itself gave no increase, and the potash salt by itself an increase of only 2,700 lb.

In any event, care must be taken not to undervalue the soil-nitrogen; for although it is, comparatively speaking, inert, it is by no means absolutely so.

Amount of Nitrogen supplied by the Soil.

Boussingault found long ago, when studying the influence of several different rotations on soils which were manured occasionally, and not very heavily, that there was more nitrogen in the crops harvested in a term of years than had been put upon the land in the manure. More recently, Thaer has estimated, from the results of many trials, that of every 100 lb. of nitrogen carried off the land in ordinary crops, about 55 lb., on the average, are derived from the soil-nitrogen, and 45 lb. from the manure. In special trials made to determine how much assimilable nitrogen could safely be applied as manure, it appeared that, during the eleven years of the experiment, 52 lb. of nitrogen were harvested, on the average, per year and per acre, while only 24 lb. of nitrogen per year were applied to the land in the manure. More than this amount of nitrogen could not be applied commonly, except at a disadvantage. Rye, indeed, bore 35 to 38 lb. of nitrogen to the acre, and oats and potatoes 43 to 52 lb., though the largest amount named did not increase the yield of potatoes. Thaer concludes that, in general, and for ordinary circumstances and conditions, about half as much nitrogen may be applied in the fertilizers as would be expected to be contained in the crop.

The vast importance of the soil-nitrogen is shown also by the fact, repeatedly insisted upon by Lawes and Gilbert, that when nitrogenous fertilizers are used for forcing crops the increase of the crop, over and above what is obtained from unmanured land, very seldom contains as much nitrogen as was put upon the land in the fertilizer. In the experiments of Lawes and Gilbert where ammonium salts, or nitrate of soda, together with mixed mineral fertilizers, were applied year after year to wheat, barley, oats, and grass, a large proportion of the applied nitrogen was not recovered in the increase of the crops harvested. When, in addition to mixed mineral fertilizers, ammonium salts were applied for 20 years in succession, at the rate of 200 lb. to the acre annually, rather less than one-third of the supplied nitrogen was recovered in the increase of the wheat-crops (over and above what was obtained by the use of the mixed minerals without any addition of ammonia), and nearly one-half in the increase of the barley-crops. With the same mineral manures and 400 lb. of ammonium salts, applied for 20 years to wheat, there was recovered in the increase, as before, scarcely one-third of the applied nitrogen. When more excessive amounts of ammonium salts were used upon wheat, notably less than one-third of the supplied nitrogen was recovered, and the greater the excess the less was the gain. In the case of barley that received, beside the minerals, 400 lb. of ammonium salts for 6 years, 200 lb. for 10 years, and 275 lb. of nitrate of soda for 4 years, there was again recovered in the increase nearly one-half of the nitrogen applied; and when 550 lb. of nitrate of soda (equal to 400 lb. of the ammonium salts) were applied in the spring, there was recovered in the increase of crop, even with wheat, not much less than half, and with oats rather more than half of the applied nitrogen.

Significance of the Soil-Nitrogen.

The following table shows the quantities of nitrogen applied annually during 20 years in the form of farmyard-manure and the quantities of nitrogen obtained annually in the crops of wheat and barley. The column headed "in produce by mineral manure" (devoid of nitrogen) shows how much nitrogen was taken from the soil itself: —

	Pounds of nitrogen per year and per acre.				For each 100 lb. nitrogen in farmyard-Manure.	
	Supplied in 14 tons of Farmyard-Manure.	In produce by Mineral Manure.	In produce by Farmyard-Manure.	In increase due to Farmyard-Manure.	Recovered in increase.	Not recovered in increase.
Wheat . . .	200.7	20.1	49.3	29.2	14.6	85.4
Barley	200.7	23.9	45.3	21.4	10.7	89.3

In the case of oats dressed with mineral fertilizers and 400 lb. of ammonium salts during 3 years, rather more than one-half of the supplied nitrogen was recovered in the increase of the crop. When rape-cake was applied for barley, a considerably less proportion of the nitrogen was recovered than when ammonium salts were used.

In the case of farmyard-manure, applied to wheat and to barley, very much less of the supplied nitrogen was recovered than was recovered from the artificial nitrogenous fertilizers. On the assumption that the dung used contained about 200 lb. of nitrogen per year and per acre, there was recovered in the increased produce of wheat only about one-seventh, and in that of barley scarcely one-ninth of the nitrogen supplied in the manure. But it is to be remembered that dung decomposes so slowly that its influence may be felt for many years. In the year 1875, Lawes and Gilbert could still perceive some slight effect due to dressings of farmyard-manure which had been applied for the last time, to pasture grass, in 1863.

The mixed herbage of an old grass-field, which as the average of 10 years yielded 2,500 lb. of hay to the acre when unmanured, took off 35 lb. of nitrogen annually. When manured with a mixture of mineral fertilizers (without nitrogen), 3,800 lb. of hay were obtained and 55 lb. of nitrogen, the increase being due no doubt to an increased growth of leguminous plants. With 400 lb. of ammonium salts and the mineral fertilizers, 6,000 lb. of hay were harvested annually, and 76 lb. of nitrogen; and with 800 lb. of ammonium salts (containing 172 lb. of nitrogen) and the minerals, the figures were 6,900 lb. of hay and 103 lb. of nitrogen, though this very large quantity of ammonia was found to be excessive and was reduced to one-half after a few years.

With mineral manure and 275 lb. nitrate of soda, the figures were 5,100 lb. hay and 63 lb. nitrogen, and when the quantity of the nitrate was increased to 550 lb., the crops were 5,900 lb. hay and 68 lb. nitrogen. In the case where 14 tons of farmyard manure to the acre were applied to the grass annually during 8 years, and no manure was applied during the next 12 years, results were obtained which are set forth in the following table: —

Lb. of Nitrogen, per acre,		
Applied in manure during 8 years . . .	1606	
Recovered in 20 years in increase of crop over that got from unmanured land .	291	18.1 %
Not recovered in increase	1365	81.9
Residue in soil 54 inches deep	529	32.9
Not recovered in increase or in the soil .	786	49.0

When 400 lb. of ammonium salts, containing 86 lb. of nitrogen, were applied per acre, without any addition of ash-ingredients, the average annual crops during 10 years were 3,400 lb. of hay containing 58 lb. of nitrogen; and when 550 lb. of nitrate of soda, containing very nearly the same quantity of nitrogen as the 400 lb. of ammonium salts, were applied without any ash-ingredients, the average crop of hay during 8 years was 4000 lb., containing 63 lb. of nitrogen. On using half as much of the nitrate, the crop was 3,800 lb. hay, containing 56 lb. of nitrogen.

So, too, in Hellriegel's experiments upon grain-plants, made with the utmost care by way of sand-culture, there was ordinarily recovered in the crops harvested about 90 % of the nitrogen which had been applied to the soil in the seed and the fertilizers; and Wolff and Kreuzhage also found in oat-plants grown in sand, fertilized with nitrates and ash-ingredients, very nearly as much nitrogen as was contained in the seeds sown and the fertilizers applied; but these observers got very different results in respect to leguminous plants grown in sand. Their leguminous crops invariably contained much more nitrogen than had been purposely added to the soil, and it is now known that leguminous crops may obtain nitrogen in a different way from grain-crops, as will be explained directly in the chapter on Symbiosis, and that they may grow quite independently of the nitrogen of the soil, or even of that applied as manure, since they are often, or perhaps usually supplied with nitrogen from the air.

Lawes and Gilbert found that root-crops usually returned to them a larger proportion of the nitrogen applied in the fertilizers than cereal crops did. In one set of experiments, for example, they grew sugar-beets five years in succession, and manured one parcel during the first three years heavily with nitrate of soda, in addition to other things; and on calculating the amount of nitrogen taken up by these five crops of beets grown with nitrate of soda, first deducting the produce grown on contiguous plots manured with ash-ingredients alone, it appeared that the quantity of nitrogen obtained was very nearly equal to the amount that had been supplied in the form of nitrate of soda.

Endurance of Farmyard-Manure.

Gasparin has reported of southeastern France, where the old Roman two-course rotation is practised, viz.: I. Wheat, II. Fallow, that land on which no manure has been put for several years comes to yield about 10 bushels of wheat to the acre, every second year. If this land is manured at the rate of 11 tons to the acre of farmyard-manure containing 110 lb. of nitrogen, the first crop of wheat will amount to 20 bushels, and nearly a ton of straw; two years later the crop will amount to 14 bushels of grain, and 1300 lb. of straw. But unless a new application of manure is made, the next crop (i. e. the crop of the fifth year) will fall back to the original 10 bushels of grain. It appears that on that soil the influence of the manure is felt for three years, and that two crops of wheat exhaust the goodness of the manure.

In the experiments of Bec, made on a poor, calcareous soil in France, 10 bushels of wheat and 830 lb. of straw to the acre were harvested on unmanured land, and the crop carried off 16 lb. of nitrogen. But on land dressed with 11 tons of farmyard-manure to the acre, whereby 110 lb. of nitrogen to the acre were applied, the next crop was 16.4 bushels of wheat, and 1275 lb. of straw, and the next year there was obtained 38.5 bushels of oats and 1637 lb. of straw. Since this oat-crop, taken the year after the wheat, carried off 28 lb. of nitrogen, it appeared that the power of manure had not been wholly exhausted, as might have been the case if the land had been left fallow and been cultivated frequently, as was done in the previous experiments relating to the old two-course rotation. The justice of this observation of Gasparin has been repeatedly illustrated in recent years by experiments on the waste of farmyard-manure in the soil through nitrification and the percolation of nitrates in the drain-water.

In another set of experiments on the same kind of soil, in place of the farmyard-manure, 660 lb. of rape-cake to the acre were applied. This fertilizer contained 45 lb. of nitrogen. There was harvested in the first year, 20 bushels of wheat and a ton of straw; and in the second year 28 bushels of oats were obtained, and 1870 lb. of straw. This oat-crop carried off 21 lb. of nitrogen, which was more than the first crop of wheat had taken from the unmanured land, though somewhat less than the oat-crop took from the land dressed with farm-manure. It appeared that the rape-cake acted a little more quickly than the manure, that its chief action was in the first year, and that the goodness of it had not been completely exhausted by the crop of the second year.

It may here be said that trials were made with guano, also, in comparison with the foregoing experiments, and that there was obtained, after a dressing of 660 lb. guano to the acre, i. e. of 79 lb. of nitrogen, a crop of 29 bushels of wheat and 2 tons of straw, and afterwards a crop of oats that yielded 30 bushels of grain and 1330 lb. of straw. Since this oat-crop of the second year carried off more nitrogen (22 lb. to the acre) than had been carried off by the corresponding crops dressed with farm-manure and oil-cake, it is evident that the virtue of the guano had not yet been completely exhausted.

Striking evidence of the extremely slow action of that very large proportion of farmyard-manure which is not put to use by crops in the first years of its application is afforded by the experiments of Lawes and Gilbert on the continuous growing of potatoes. During 6 consecutive years, the land received annually 14 long tons of farmyard-manure, estimated to contain about 200 lb. of nitrogen, and there were harvested per year and per acre, 5 tons and 5 cwt. of tubers on the average. During the next 6 years, no manure was put upon the land, and the crops during these years weighed 3 tons and 1 cwt. on the average, a quantity which was less than the average produce obtained by using a mixture of mineral fertilizers that contained no nitrogen. All of which goes to show that a large part of the mineral matter in manure, as well as much of the nitrogen, is not readily assimilable by plants; or, at the least, that it is not easily assimilable after having lain in contact with the soil during several years.

In their experiments on barley also, after farmyard-manure had been applied continuously during 20 years, the plot was divided, and thenceforth one-half of it got no manure, while the other half was manured as before. Ten years after the last application of the manure, the effect produced by the residues of the old manurings was still very apparent in the size of the crops, and the soil was then found to contain more nitrogen and more nitrates than any other plot in the field, with the exception only of the one continuously dressed with farmyard-manure.

Some Crops use Soil-Nitrogen freely.

Not only is it a fact of familiar observation that the soil-nitrogen is useful, but it has been shown repeatedly by methodical experiments that very large quantities of nitrogen are often taken off in crops from land which has received no manure whatever. Thus it was found by Lawes and Gilbert that wheat grown upon one piece of unmanured land for 32 years in succession took off, on the average, 21 lb. of nitrogen per year and per acre, — more than 600 lb. in all, it will be noticed. Upon an adjacent plot that was dressed with a mixture of mineral manures, the wheat-crop took off 22 lb. of nitrogen per year and acre.

A barley-crop took off 18⅓ lb. and 22⅓ lb. of nitrogen per year during 24 years, when unmanured and when manured with ash-ingredients.

A series of root-crops took off 27 lb. of nitrogen per year during 31 years, from a plot manured with ash-ingredients.

Beans took off 31⅓ lb. of nitrogen per year from unmanured land during 24 years, and 45½ lb. from land dressed with mineral fertilizers.

Red clover took off annually, during 22 years, 30.5 lb. from unmanured land, and 40 lb. from land dressed with mineral fertilizers.

Gradual Exhaustion of Soil-Nitrogen.

It was noticed, furthermore, that, during these long terms of cultivation, rather more nitrogen was taken off in the crops during the earlier years than was taken toward the close of the term. Thus, while the unmanured wheat-crop took off 21 lb. of nitrogen per year on the average of 31 years, it took off 25¼ lb. on the average of the first 8 years, and 23 lb. on the average of the first 12 years.

It would seem, therefore, that the nitrogen in the soil, derived from previous accumulations, was gradually used up by the continued cropping; and in fact, careful analyses, made at different periods of the soil of the fields where these experiments were conducted, showed conclusively that there was an appreciable reduction of the amount of nitrogen in the soil as the years went on. After 40 years' persistent cropping of the good land with wheat, it appeared that the original stock of organic nitrogen (as well as the stock of potash and phosphoric acid) had been considerably reduced, although there was still left enough of all these constituents to indicate that wheat might be grown on that land for a very long period.

Warington has remarked that the fact that wheat can be continuously grown on such a soil with fair results is due to the small demands of the crop and to its great capacity for appropriating the mineral food of the soil; and it will be well to bear in mind also the fact that the power of the wheat-plant thus to appropriate food depends in good part on the circumstance, that the soil is usually fairly well charged with moisture during those months when the crop is growing. In experiments on the 4-course rotation where the land was unmanured during 44 years and all the produce was removed, wheat was the crop which gave the largest weight of produce per acre during this long period. The practical difficulty attending the continuous growing of wheat in England is that of keeping the land clean, and this difficulty is of course greatest upon a heavy soil, in a moist climate, and with a poor wheat-crop.

There is of course an essential difference between cultivated land, from which crops are continually taken, and wild land upon which plants grow and die and decay and so give back every year the food they had taken from the soil. In actual farm practice manure is applied to compensate for the materials which crops remove.

Running out of Land.

The using up of the soil-nitrogen by excessive or injudicious cropping is usually the cause of the so-called "running out" of land. Unless land contains in the beginning an abundant store of fertility, and particularly a great reservoir of humus, and unless ameliorating crops are grown upon it occasionally, the nitrogen will waste away and the land will fall into bad condition. Every year a certain proportion of the nitrogen in the organic matters in the soil is nitrified by the action of the microscopic ferments, and while a part of the nitrates thus formed is consumed by the growing crops, another part is washed out of the land in the drain-water, especially in wet seasons, some portion of the nitrogen may become more inert than it was in the beginning, and still another part may be reduced and destroyed by useless fermentations.

As Lawes and Gilbert have said, "soils contain nitrogenous matters which nitrify with different degrees of facility. The bulk of the nitrogenous matter of soil is only capable of very slow oxidation, but a smaller proportion is far more readily converted into nitrates. In thoroughly exhausted land the easily nitrifiable matter has to a large extent disappeared, while on soils in good agricultural condition it is continually renewed by fresh crop-residues or by the application of organic manures. This easily nitrifiable matter constitutes a chief part of the floating capital of the soil, on which its immediate productiveness depends. The larger quantity of more inert nitrogenous matter constitutes the sunk capital which only very slowly becomes available."

An idea of the rate at which soil-nitrogen, taken from fertile fields, may be changed to nitrates under favorable conditions — as compared with the rapid nitrification of farmyard-manure in similar fields — may be got from the results of some experiments made by Dehérain on different kinds of soils, as stated in the following table. One series of well-drained jars of glazed earthenware was charged with the unmanured soils to be examined, 50 kilos. of earth being placed in each jar; while another series of similar jars was charged with 50 kilos. portions of mixtures of the soils and farmyard-manure. Into each of these mixtures there had been put one kilo. of the manure which contained 5 grm. of nitrogen. All the jars were kept free from vegetation and were maintained under conditions favorable for nitrification. The figures of the table represent the quantities of nitrate-nitrogen which passed out from the soils in the drainage-waters during the months March to October: —

Kind of Soil.	Milligrams of Nitrate-nitrogen in the drain-water from the soils when Manured.	Unmanured.
Light, somewhat calcareous . . .	2224	1131
Strong, clayey	1307	595
Strong, rich in humus	1411	660
" from another locality . .	1205	727

Whence it appears that under the exceptionally favorable conditions of the experiment about one-half of the nitrate-nitrogen in the drain-waters came from the nitrogenous matters natural to the soils, and the other half from the manure. It appeared furthermore, even in the very most favorable instance of the light calcareous soil, that only one-fifth part of the nitrogen of the manure was nitrified during the year of its application, while four-fifths of it remained in the soil to be gradually oxidized in subsequent years, and so to re-enforce future applications of manure. In two of the other instances one-seventh of the nitrogen of the manure was nitrified, and in the last instance one-tenth, in the first year.

Since, in attempting to grow root-crops without any manure, the produce falls off to next to nothing after a few years, the figures of Lawes and Gilbert, as cited above, refer to the plot that was dressed with a complex mineral fertilizer, and in this case much more nitrogen was taken off during the earlier than in the later years.

During the first 8 years of turnips, the average yield of nitrogen was 42 lb. each year. During the next 3 years the land carried barley, which yielded 24½ lb. of nitrogen per year. During the next 15 years, 13 of which were with Swedish turnips, and 2 without any crop, there was a yield of 18¼ lb. of nitrogen per year, and during the last 5 years sugar-beets yielded 13 lb. of nitrogen per year. Here there was a reduction to less than one-third during the later years, as compared with the earlier. Lawes and Gilbert found, furthermore, that the root-crops exhaust the upper layers of the soil of their available supplies of nitrogen more completely than any other kind of crops.

Clover and beans, on the other hand, and in general the leguminous crops, did not thus exhaust the surface soil of nitrogen, but seemed to get their supplies from below. As we now know, these crops support upon their roots certain micro-organisms which are capable of obtaining nitrogen from the air. Thanks to the action of these organisms, the surface-soil is left by a clover-crop richer in nitrogen than it was before.

Large Amounts of Nitrogen in Good Soils.

Attention has often been called to the very large amounts of reserve nitrogen that occur in cultivated soils. Krocker, and Payen also, showed long ago that they rarely contain less than 0.1 % of nitrogen (say 3,500 lb. to the acre, taking the loam as one foot deep), and that they usually contain a much larger quantity. A. Mueller found, on the average, 0.26 % of nitrogen in the surface-soils of regions poor in lime, and 0.15 % in their subsoils. In the surface-soils of limestone regions he found, on the average, 0.66 % of nitrogen. In several instances he found from 0.9 to 0.96 %. Mueller's averages for the surface-soils are equivalent to 3.7 % and 4.6 % of the organic matter in the soils. From the analyses of a large number of soils taken from sugar-beet fields in all parts of Germany, Grouven has shown that the proportion of nitrogen in the humus of good soils ranges from 1.7 to 7.2 %. The average of his analyses was 3.6 %. Boussingault, also, on analyzing a number of loams of good quality from widely different localities, found from 6,000 lb. to more than 30,000 lb. of nitrogen to the acre, taken to the depth of 14 inches, which was in the more or less inert condition above described. All this nitrogen is naturally to be thought of as additional to the comparatively small amounts of nitrates and ammonium compounds which are usually found in loams.

In this country, Hilgard and Jaffa have found from 1.25 to 5 % of actual humus, in soils from humid regions that were fairly well charged with humus, and that the proportion of nitrogen in this humus is, on the average, about 5 %, while, as has been said, they find almost 16 % of nitrogen in the humus of arid upland soils from California; whence it appears that these arid soils are really well provided with nitrogen, although the quantity of humus may amount to no more than 0.75 % of the soil.

Loam may contain as much Nitrogen as Manure does.

On comparing good, cultivable soils with farmyard-manure, it will be found not infrequently that, weight for weight, the soil contains as much nitrogen as the manure. Even when, as commonly happens, there are two or three times as much nitrogen in a given weight of farmyard-manure as in the same weight of the soil to which it is applied, it will still remain true that the absolute addition of nitrogen to that already in the soil, which is made by an ordinary application of farmyard-manure, is extremely small, i. e.

as compared with the great mass of nitrogen already in the land. It is the superior quality of the dung-nitrogen and, doubtless, the ferment-organisms which manure brings to the land, as well as the action of the manure to hold moisture in the soil, which make the use of the dung so very important. Anderson determined, according to one and the same definite plan, the amounts of nitrogen and of organic matter in soils and manures taken from 8 different farms in Scotland, and obtained the results, which are given in the following table: —

	Organic Matter %.	Nitrogen %.
The soil from farm *a* contained	5.97	0.14
The manure from farm *a* "	20.17	0.41
The soil from farm *b* "	5.67	0.15
The manure from farm *b* "	15.24	0.46
The soil from farm *c* "	5.69	0.14
The manure from farm *c* "	11.19	0.49
The soil from farm *d* "	9.85	0.29
The manure from farm *d* "	21.68	0.49
The soil from farm *e* "	4.96	0.22
The manure from farm *e* "	7.24	0.19
The soil from farm *f* "	9.65	0.27
The manure from farm *f* "	11.39	0.34
The soil from farm *g* "	6.36	0.18
The manure from farm *g* "	11.47	0.32
The soil from farm *h* "	8.50	0.26
The manure from farm *h* "	13.17	0.36

Enormous Importance of the Soil-Nitrogen.

Under fit conditions as to tillage and crops, and with suitable additions to the soil of phosphates or potash compounds (or both) to promote the growth of the microdemes which cause fermentation, these great stores of soil-nitrogen, which are so abundant that they might almost be regarded as inexhaustible, become gradually available for feeding crops. There is hardly a more important problem in agriculture to-day than the perfecting of methods for using these great natural supplies of nitrogen to the best possible advantage, although it is true that already, from time immemorial, cultivators have often found it to be more advantageous and more economical to improve the quality of the soil-nitrogen by tillage combined with fallows and rotations, than to buy fertilizers, or than to keep cattle for the sake of producing more manure. See, also, the chapter on Symbiosis.

Peat as a Source of Nitrogen.

It is not in arable loams alone, and in leaf-mould, that the inert nitrogen compounds are found. Here in New England, great quantities of them are to be had, at small cost, in the form of peat, swamp-mud, or marsh-mud, as well as in the form of old sods taken from headlands and from beside walls; and upon many excellent farms it was customary formerly to put such materials to use. Indeed, peat deserves to be treated of as a nitrogenized manure as much as several of the substances which have been mentioned in the preceding pages.

As here used, the term peat applies to any bog-earth of vegetable origin; it includes bog-meadow-mud and marsh-mud, as well as the more perfect peats, about the naming of which there could be no question. The New England term "muck," of course, falls within the above definition. In the Queen's English, the word muck simply means manure, i. e. well-rotted dung. Excepting in the fens of Lincolnshire, it has no special reference to any kind of peat or bog-mud. The New England application of the word to bog-earth is a mere provincialism, natural enough in a land of hungry gravels, where custom requires the farmer to try to cultivate 4 or 5 times as much land as he can manure from his barnyard.

It happens, too, as Professor Johnson has urged, that in New England the number of small, shallow depressions, containing unripe or impure peat, is much greater than that of large, deep bogs. Our farmers are, in fact, more accustomed to the class of deposits which they call "mucky," than to those that would be called peat by everybody without question. It may be said that peat, no matter of what grade, almost always contains a considerable quantity of nitrogen.

A moment's consideration as to the mode of formation of peat teaches that this must be so, for all kinds of peat have resulted from the partial decay of vegetable matters. Peat is formed in boggy places where water stands at rest. In this water, successive crops of various aquatic mosses grow, often with great rapidity, and they die where they have grown, in such wise that great accumulations of partially decomposed vegetable matter result. It has been said of certain bogs in Hanover, that the trenches from which peat has been dug fill up again every 30 years to a depth of 4 to 6 feet with new accumulations of peat. (Stamm.) In like manner, the extremely rapid growth of peat in Scotland has been insisted on by Angus Smith.

It is easy to see that peats and peaty soils formed in this way will be likely to contain appreciable quantities of nitrogen, while they will commonly be poor in inorganic matters, unless, indeed, sand or clay or silt happens to have been washed in upon them during or subsequent to their formation.

Analyses of Peat.

In 30 samples of peat, of all sorts and kinds, analyzed at the Yale laboratory under Professor Johnson's direction, the proportion of nitrogen varied from 0.4 to 2.9 %. The average amount of nitrogen was 1.5 % of the air-dried peat; or more than three times as much as is contained in ordinary barnyard-manure. In several of the peats the amount of nitrogen was as high as 2.4 %; the low average percentage just given was due to the fact that many of the samples analyzed were of manifestly poor quality. Fully one-half of the specimens were largely mixed with soil, and contained from 15 to 60 % of mineral matters. One was a sample of mud from a salt-marsh, and it contained 1.4 % of nitrogen.

It is a matter of experience, however, that peats are occasionally met with that contain comparatively little nitrogen. Mulder, for example, mentions a brown peat from Friesland, which on being leached with soda-lye yielded humic acids which contained no more than a trace of nitrogen. Hence, in case a farmer should happen to have several kinds of peat to choose between he might do well to scrutinize each of them carefully and to prove by experiment which of them is best suited to his purposes. Generally speaking, by far the larger part of the nitrogen in peat exists in a form that is insoluble in water, and comparatively inert, considered as a source of plant-food. In spite, however, of this inertness, it is a matter of familiar observation and experience, that the peat-nitrogen may be made to contribute to the support of crops, and that it has consequently a considerable money value.

Peat undergoes Change in the Air.

It would appear that when peat is exposed to the action of the air, as when mixed with any ordinary cultivated soil, its nitrogen slowly undergoes change, and that some of it is gradually made available for the plant, much in the same way that the nitrogen of rags or of bone-meal would be under similar conditions. With regard to this point, it should be said that investigations by Nessler have shown that, although the nitrogenous constituents of peat decompose in the soil more slowly than the altered ossein in meal from steamed bones, they do nevertheless in some cases decompose more quickly than the nitrogenous components of wool, or than the ossein in coarse meal from raw bones, or than those in leather-meal, either that from crude leather or from torrefied leather.

According to Marchal, through the action of the bacteria proper to such soils, the nitrogenous constituents in the humus of mellow sandy loams are changed to ammonia together with small quantities of peptones, leucin, tyrosin and fatty acids. The most favorable conditions for the activity of these bacteria are moisture, a temperature of about 86° F., adequate access of air and a slight alkalinity. In sour humus changes of somewhat different character occur, and they are to be attributed to a considerable extent to the action of moulds which suffer much less from the presence of acids than the bacteria do. It is easy, in any event, to hasten this process of conversion into plant-food by neutralizing the natural acidity of the peat by means of an alkali, such as lime, wood-ashes, or potashes; or by composting the peat with dung, or fish, or flesh, as will be explained under the head of Composts.

It is to be inferred, moreover, from the observations of Brunnemann, that some of the nitrogen in moor-earth may be made available as plant-food by the action of non-alkaline potash salts, such as the sulphate and the chloride. To test this matter, Hess mixed samples of moor-earth with kainit, and with potassium sulphate and chloride, as well as with gypsum, with lime, and carbonate of lime. He kept the moist mixtures in glass bottles for a year and a half and then leached them with water, in order to determine how much of the nitrogen of the humus had become soluble. It appeared that, from the mixtures which contained potash salts, water dissolved out about 8 times as much nitrogen as could be dissolved from the plain moor-earth, and even that considerable quantities could be dissolved from the mixture which contained gypsum. It was noticed that the amount of organic matter dissolved was proportional to the amount of nitrogen dissolved, and that the solutions contained much acid. But since the quantities of nitrogen corresponded with those of acid, there was evidently some kind of connection between the nitrogen and the acid. It is not impossible indeed that the dissolved nitrogen may have been in the form of a base or bases similar to those detected by Loges in humus.

Hess noticed furthermore that large quantities of lime as well as of nitrogen were dissolved out by water from the moor-earth which had been mixed with sulphates and chlorides. Indeed almost the whole of the lime in the earth was removed in this way. As regards the jars which contained quicklime, or carbonate of lime, and moor-earth, it was observed a few weeks after the mixtures had been made that there was formed a brown, glutinous substance of offensive odor. But it was thought that this substance decomposed subsequently, for, at the end of the year and a half, no more nitrogen could be dissolved out from these mixtures by means of water than was got from moor-earth alone.

Some Peats readily evolve Ammonia.

For some kinds of peat, at least, it is true that ammonia may be formed from their nitrogen compounds continually, when the peat is kept in a warm place and exposed to air and moisture. In many cases this formation of ammonia from the inert nitrogen in the peat probably depends on the action of micro-organisms, as in the experiments of Selmi and other observers. But in other instances the ammonia appears to be derived from an actual splitting or *dédoublement* of the inert nitrogen compounds, i. e. to the breaking up of amids, as was probably the case in certain experiments of my own where the conditions as regards temperature excluded all living things.

It may here be said that Brunnemann, on drying moor-earth at tolerably high temperatures, found that a part of the inert nitrogen compounds in it became soluble in water. Tacke also found on heating moor-earth in water that as much as 1 % of it became soluble at 104° F., and that as much as 6 % became soluble at temperatures between 194 and 212°. Under a pressure of one and a half atmospheres (= 234°) 10.2 % of the moor-earth dissolved, and under three atmospheres (= 273°) 16 %. Meanwhile small quantities of ammonia were set free

Valuation of the Nitrogen in Peat.

If the value of the pound of nitrogen in peat be estimated no higher than five cents, that would make the ton of air-dried peat which contains 2.5 % of nitrogen worth $2.50, for this ingredient alone, to say nothing of the other useful qualities of peat which depend upon the humus contained in it, as will be explained in another place. For the present, the discussion relates only to peat in its character of a nitrogenized fertilizer, and it is to be remembered that the most valuable manures, from the money point of view, are those which contain the most nitrogen. The nitrogenized manures, such as guano, nitrate of soda, ammonia salts, blood, and flesh, cost more money per ton than any others, for the simple reason that concentrated nitrogen compounds capable of supplying this element to plants, are neither abundant nor readily prepared.

New sources of phosphate of lime have continually been discovered, so that the price of this article has not risen from year to year, in spite of the greatly extended use of it. But the assimilable nitrogen compounds are more costly than either phosphates or potash salts, and there is no immediate probability that their price will be much reduced. Hence the importance of recognizing clearly the value of the peat and the humus which are found already in the fields.

CHAPTER XV.

SYMBIOSIS, OR BLENDED GROWTH.

THE observation is as old as history that certain animals of unlike species may live together, on more or less intimate terms, to the advantage of both, as associates, messmates, or helpmeets. Thus, a troop of jackals may keep company with a lion, and by their yelping guide him to the prey, for the sake of participating in some small measure at the feast. A little plover lives with the Egyptian crocodile, and by his cry gives warning of the approach of enemies, for the sake of food which it picks off fearlessly from the reptile's teeth. Naturalists are familiar with numerous instances among the lower orders of animals where individuals of different species live together, and render each some service to their associates. It is a common thing, for example, to find minute crabs and other crustaceans living, for the sake of protection, within the envelopes of shell-fish and of various other mollusks. But many fragments of the food which the crab has captured are put to profit by the mollusk, whence it appears that guest and host do mutually help one another.

Much in the same way that this commensalism occurs among the lower animals, so also among plants examples of mutual dependence are far from being rare. It has long been known, for example, that the roots of certain parasitic plants penetrate the tissues of the plants to which they are attached so deeply, and fuse with them so completely, that the parasite has no difficulty in obtaining from its host ample supplies of water and of food, as if it were really part and parcel of the plant on which it grows. It is to be presumed, on the other hand, that in many cases matters taken in from the air by the green leaves of a parasite do actually help in some small degree to nourish the tree or other plant on which the parasite is growing.

Grafts are Parasites.

In the familiar instance of a tree or plant which has been grafted, the growth of the graft is manifestly analogous to that of the parasite just mentioned, since the leaves and stems of the graft are nourished by food taken in from the soil through the roots of the stock, while the roots and other tissues of the stock are supported in their turn by food taken in from the air through the leaves of the graft. There is a double meaning in Lord Bacon's dictum that, "The Cion overruleth the stocke quite; the stocke is but passive onely, and giveth aliment, but no motion to the graft." As Sir Humphry Davy insisted long ago, "The ilex, or evergreen oak, preserves its leaves through the winter, even when grafted upon the common oak; and in consequence of the operation of the leaves, there is a constant motion of the sap towards the ilex." This fact, it will be noticed, has a certain analogy to the old European observation, that when a single branch of a grape-vine, or of a tree, is introduced in the winter into a green-house, while the trunk and the other branches are left outside, the buds upon the heated branch will gradually unfold into leaves. (Davy.) It is manifest that the grafted plant affords a capital example of blended growth, for the scion and the stock are really two individual plants which grow one upon the other and which support one another.

During the last few years no little attention has been paid to the subject of compounded growths, and results of very great interest and importance have been arrived at; and the term Symbiosis[1] has been employed as a convenient expression to designate the whole class of phenomena which depend upon the blended growth of unlike plants.

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[1] From *βίος*, *life*, and *σύν*, *with* or *together*; i. e. *living with*.

Lichens are Compounded Plants.

As one example of this idea may be cited a theory propounded some years ago by Schwendener, that lichens are really not simple, independent, individual plants, but compound organisms, consisting of unicellular algæ enveloped and imprisoned by a parasitic fungus. In this point of view, each lichen is a colony of mixed fungi and algæ which are in some part dependent upon one another for food. A colony of this kind may consist of hundreds or thousands of individuals; but among them a fungus of the order Ascomycetes acts as a master, and is supplied with food by the algæ. This fungus surrounds and encloses the green algæ with a fibrous net of narrow meshes, as if it were a spider's web, but unlike the spider, which sucks its prey and leaves only the dead outer covering, the fungus incites the alga to active growth and to vigorous increase, while itself deriving food from it. Schwendener's theory is of no small interest historically, because from it probably has been derived the modern view as to the interdependence of fungi and various kinds of trees and leguminous plants. There can now be very little doubt that lichens are constantly supplied with nitrogen from the air, in a manner to be explained directly; and there is no longer any difficulty in conceiving how it is that they are able to grow as they do on bare rocks, far removed from vegetable mould, or any other source of combined nitrogen. As will be seen below, it has now been discovered how it is that the nitrogen of the air has been made to serve for the development of the various forms of vegetable and animal life which have existed on the globe.

Fungi Feed on Organic Matter.

It is a well-established fact that the whole class of fungi — that is to say, mushrooms, toadstools, and numberless microcsopic organisms of analogous character — can feed directly upon organic matters, such as humus, for example, and that they can assimilate both the carbon and the nitrogen which are contained in organic matters. Pasteur has shown, for example, that many micro-organisms readily assimilate the carbon of sugar and of tartrates, as well as the nitrogen in albuminoids, and in salts of ammonia, or of ethylamin. He found that the microbes prosper and produce albuminoids, carbohydrates, fats and all the other constituents proper to them, when grown in a solution which contains nothing but tartrate of ammonia and ash-ingredients.

Naegeli also found that the micro-organisms can assimilate carbon and nitrogen from acetate of ammonia, and several other ammonium salts, viz., the succinate, tartrate, glycollate, and kinate. He has shown indeed, that in the presence of ammonia, the micro-organisms can assimilate carbon from almost all compounds of this element, which are soluble in water, and are neither too poisonous nor too acid, nor too alkaline. Sugar, mannite, glycerin, and butylalcohol, are good forms of carbonaceous food for microbes; but, as a general rule, neither carbonic acid, cyanogen, urea, formic acid, nor oxalic acid are suitable for them, though they can take nitrogen from urea. From asparagin, however, and from leucin, proplyamin and the like, they take both carbon and nitrogen.

The moulds prosper in solutions which are noticeably acid, and even yeast can change sugar to alcohol in presence of weak acids; but for the growth of bacteria, a certain degree of alkalinity is necessary. Naegeli found that the moulds can take nitrogen as well as carbon, not only from albuminoids, peptones, leucin, and the like, but from all compounds of amids, amins, and ammonia; but they cannot use the nitrogen of alkaloids, cyanides, and nitro-substitution compounds. Loew, also, has enumerated the following substances that can serve as sources of nitrogen for the multiplication of vegetable cells: Ammonium salts, nitrils, amido-acids, amins, ureas, guanidins, alkaloids, nitrates and nitrites. It is to be said, however, that different kinds of fungi differ very decidedly in respect to their preferences for nitrogenous foods; and that while moulds feed readily upon nitrogenous organic matters and ammonium compounds, and on nitrates also, there are certain yeasts which grow but slowly when fed with ammonium compounds, and which are wholly incapable of using nitrate-nitrogen (A. Mayer), though they can feed upon the nitrogen of soluble organic compounds, such as peptones. Laurent suggests that the apparent inability of the yeasts to use nitrate-nitrogen may depend upon the facts that nitrates are reduced by yeasts to nitrites, and that in an acid liquor nitrous acid would be set free; which, as he finds, is a poison for the yeast-plant. It is to be noticed, on the other hand, that free nitrous acid is less liable to trouble the bacteria, since these organisms work not to acidify, but to make alkaline, the liquids in which they live.

As regards inorganic nitrogen compounds, Loew believes that fungi are nourished only by those kinds which change readily to ammonia in the cells. He finds that, while ammonia is an excellent food for fungi, the nearly related hydroxylamin acts as an intense poison, because it reacts on certain aldehyde groups which are concerned in the building up of albumen. For the same reason, both diamid and phenyl-hydrazin are poisonous to yeasts. In certain cases, where the food of fungi is rich in hydrogen, it may happen that nitrates may serve a better purpose than ammonia salts. But in all cases in which nitrate-nitrogen is put to use by fungi, the nitrate appears to be first reduced to the condition of ammonia; and in this reduction there appear to be two steps, viz., first, the formation of a nitrite, and subsequently an ammonium compound.

It is not impossible that the study of these diversities among microscopic organisms, especially when taken in connection with the phenomena which relate to the blended growth of roots and fungi, may throw some light upon the question, previously discussed, why some kinds of crops can get more profit from ammonium salts than from nitrates. According to Schloesing, even the moulds prefer ammonia-nitrogen to nitrate-nitrogen. Ordinary beer-yeast can take nitrogen both from ammonia compounds and from organic compounds which yield ammonia by decomposition, — such as urea, guanin, allantoin, asparagin, and uric acid, but not from leucin, creatin, caffein, or other alkaloids; nor can beer-yeast feed upon albuminoids directly, though it is easily supported by soluble modifications of the albuminoids, — such as peptones. (A. Mayer.) It has been noticed, as a general rule, that those organic compounds which contain but little oxygen, though rich in carbon and hydrogen, and those which are insoluble or difficultly soluble in water are not good materials for the support of fungi.

Fungi on the Roots of Forest-Trees.

It has been observed that to the roots of many kinds of forest-trees certain fungi are often attached in such manner that the fungus conveys food to the tree upon which it is itself subsisting. Indeed, fungi have been found growing in this way, not only upon the oak, beech, hornbeam, birch, and alder, but also on evergreens, — such as the fir, pine, spruce, and larch. Doubtless there are several different kinds of fungi parasitic upon the roots of trees or other plants which act in this way and supply nitrogenous food to their hosts; and it has been noticed that the roots of trees thus beset with the fungus are ordinarily destitute of the fine hairs which abound upon the roots of most plants, and which serve the purpose of taking in food and water from the soil. In some instances, in place of the root-hairs, a thick coating of the mycelium of a fungus covers the surface of the roots. The filaments of the mycelium not only penetrate the spaces between the cells of the epidermis of the root and surround these cells, but they reach out also into the soil in which the roots are growing, as if for the purpose of taking nourishment from the soil. It would seem, indeed, as if the fungus-mycelium here took the place of the root-hairs of ordinary plants, and that it did the work of the root-hairs, and more. In other cases, a nitrogen-bringing bacterium lives within the tree-root, and evidently subsists upon the juices therein contained.

Woodland Humus is devoid of Nitrates.

As bearing upon the question now under discussion, it is noteworthy that the humus of woodland is apt to contain no more than very small amounts of nitrates, such as support most agricultural crops. In other words, those kinds of plants which need nitrates grow most freely in situations where nitrates form readily; while those plants which can get food through the root-fungi need less nitrate-nitrogen than others, and can prosper in places where nitrates are scarce, though fungi abound.

This coating of the roots of forest-trees by the fungus-mycelium has been noticed both on high land and on low land, under the most varied conditions as to moisture, and it is thought to be a general fact; but it is still true that the coating is seen to be specially well-developed in soils that are rich in humus, while it may fail altogether in sterile soils, which contain but little organic matter. Moreover, on transplanting young trees that have roots thus coated into a soil poor in humus, or into water properly charged with plant-food, the fungus will speedily disappear, while the trees continue to grow normally. That is to say, these trees may either take food directly from the soil or they may get it indirectly through the intervention of a fungus; and both these modes of nourishment may be in action simultaneously, and in equal degree, or one of them may become more prominent than the other, in case circumstances should favor it. A familiar example of the improvement of land through the action of a root-fungus is seen here in New England in the case of the common alder (Alnus). On pulling up a clump of old alders growing in a wild pasture, it will often be noticed that the appearance of the soil about their roots is surprisingly good. It is said that a striking instance of a plant which is supported in good part by its root-fungus is seen in the case of Monotropa hypopitys (yellow birdsnest), which grows among dead leaves and half-decaying vegetable mould. It has neither leaves nor chlorophyl grains; but it has been suggested that, like the trees now in question, it has roots which are covered with fungus-mycelium, by means of which it obtains carbon and nitrogen from the humus of the soil.

Lumps on Clover-Roots.

Yet again, botanists have often speculated as to the function of certain lumps, knobs, warts, nodules, or tubercles which are observed upon the roots of clover, lupines, and other leguminous plants. The German physiologist Lachmann studied them particularly in 1858. In England, Berkeley wrote of them, in 1863, as follows: "There is a circumstance about most leguminous plants which has not yet been sufficiently studied. From the earliest period of growth little tuberiform bodies are formed upon the roots, which have been described as fungi. They sometimes acquire a considerable size, as in the common acacia. . . These bodies are doubtless occasionally important organs in time of drought, though it is very possible, as many of them become effete at an early period, that they serve some especial object beside. Desmazières, many years since, pointed out to me some curiously shaped, extremely minute bodies to which they give rise. . . Something very analogous occurs in many conifers."

Bacteria in the Root-nodules take Nitrogen from the Air.

It has frequently been suggested that the knobs on the roots of clover, etc., must be due to a diseased condition of the plant, though it has really long been known that the knobs do crops no harm, and that they are apt to be specially abundant upon those plants which are precisely the healthiest and the most vigorous. Some persons have thought that the knobs should be regarded as reservoirs of food, while others have urged that they are normal organs, though peculiar to leguminous plants. This last-named view may be accepted as not far from correct; for the knobs may well be regarded as special organs, begotton it is true by a parasite, but developed by the reciprocal action of the parasite and the plant.

It has been thoroughly well made out that certain kinds of bacteria enter the roots of leguminous plants from the soil and form colonies within the roots, and that the knobs are formed by the simultaneous development of these bacteria and of the vegetable cells in the root, — that is to say, by the reactions of the bacteria and the cells one upon the other. It has been made plain, withal, that both the bacteria and the plant itself derive profit from the reactions; for while the bacteria feed upon the plant and derive most of their food from substances formed within it, they do also take nitrogen from the air; and a part of the nitrogen thus collected is consumed and put to profit by the plant, which in this way feeds upon or through its own parasite. The practical result of the symbiotic growth in this case is that the micro-organism on the clover-roots takes free nitrogen from the air and assimilates it in such manner as to form fit food for the clover plant, which readily partakes of the food thus offered, and derives great advantage from it.

It may here be remarked that certain micro-organisms are known, which, when fed with sugar, out of contact with any plant, can assimilate free nitrogen from the air. Hence the power of the nodule-bacterium to take sugar etc. from plant-sap may well be regarded as a particular instance of this kind of feeding. Lachmann appears to have been the first to suspect, in 1858, that the nodules might possibly be connected in some way with the taking in of nitrogen by plants, and his remark was recalled by Rautenberg and Kuehn, in 1864, on noticing that bean-plants, grown by them by way of water-culture, had nodules on their roots only in those cases in which the plants were standing in solutions to which no compound of nitrogen had been added.

The Root-nodules contain much Nitrogen.

Even before the foregoing fact was discovered, De Vries had noticed that the nodules contain very considerable quantities of albumen, so long, at least, as the plant to which they are attached is growing, although finally, when the plant begins to ripen its seeds, most of the albumen passes out from the nodules into the plant. For that matter, the nitrogenous character of the nodules is indicated by the fact that, in the fields, they are constantly eaten into by insects and worms. (Prazmowski.) De Vries observed, furthermore, as others had done, that comparatively few nodules seemed to be developed on plants so situated that they can get an abundance of nitrate-nitrogen directly from the soil.

Analyses made by Troschke of the knobs on lupine roots, and of the roots themselves on which the knobs had formed, show that the knobs contain much more nitrogen, phosphoric acid, etc., than the plain roots, and that they are really highly stored with plant-food. Some of Troschke's results are given in the following table:—

	Roots. %	Knobs on Roots. %
Ashes	4.07	7.51
Fat	1.31	5.33
Nitrogen	1.13	7.25
Carbohydrates	34.61	32.42
Cellulose	52.95	9.43
Phosphoric acid in the ash	8.84	16.19
Potash in the ash	12.80	16.90

Hellriegel's Discovery.

The investigation of these nodules has become a matter of the utmost importance now that numerous and irreproachable experiments have shown beyond all question that, by means of micro-organisms which live in the nodules, various kinds of leguminous crops can readily obtain from the free nitrogen of the air all the nitrogen which is needed for their perfect development. On making proper allowances for the conditions which are requisite for the comfort and prosperity of the micro-organism, it is now an easy matter to grow leguminous plants in mere sand, which is of itself wholly free from nitrogenous matters, provided only that suitable ash-ingredients have been mixed with the sand, and that it has been "seeded," as the term is, with the germs of the micro-organism.

It is to the German chemist Hellriegel that we owe the discovery of this most important fact. He has proved, by means of extremely careful and painstaking experiments, that various kinds of leguminous plants do constantly obtain nitrogen from the air by means of living organisms which subsist upon their roots; and has shown that large quantities of nitrogen are actually accumulated from the air in this way by leguminous crops, even when these crops are grown in sand which is wholly free from organic matter and from compounds of nitrogen. He observed, furthermore, that nodules form upon the roots of the plants at the times when nitrogen is being taken from the air, and that these nodules are filled with bacteria.

Hellriegel's method of experimenting was to sow seeds of various kinds in pure sand which contained no nitrogen whatsoever, but which had been charged with ash-ingredients proper for the support of crops. All the seeds thus planted germinated readily in the moistened sand, and the young plants grew well enough until the store of nitrogen proper to the seed had been exhausted,—that is to say, the young plants grew until several leaves had formed. But from this time forth most of the plants simply starved. They no longer grew freely; and it was evident that the sparse formation of new portions of stem or of leaf was dependent on the taking of matter from the older leaves. Yet, on adding to young pea-plants, thus standing in a starving condition, a minute quantity of water which had recently been in contact with garden loam, taken from a field where peas and clover had often been grown in previous years, the experimental plants were soon seen to take on a dark-green color, and to grow luxuriantly from that time forth until the period of ripening. Meanwhile, nodules grew freely upon the roots of the thriving pea-plants, although none had grown so long as the plants remained in the condition of starvation.

Loam contains the Nitrogen-bringing Bacteria.

To state the matter more precisely, the loam-water contains certain microscopic organisms which enter the pea-roots and develop colonies there, and these colonies of bacteria are speedily enclosed in nodules which form about them. But the bacteria in the nodules thrive upon the substance of the pea-plant and upon free nitrogen which they take from the air; and the pea-plant, in its turn, feeds upon the substance of the bacteria, and gets nitrogen enough therefrom for all its needs.

In the case of starving peas, to which no loam-water was added, it occasionally happened that germs which had been floating in the air fell upon the soil in which the plants were standing, and caused them to revive; but this accident was readily avoided by sterilizing the soil in the first place, and keeping it covered with a sheet of sterilized batting. So, too, on boiling the loam-water, in order to kill all living things which were contained in it, its power to make pea-plants grow was destroyed, — that is to say, by taking care to exclude from the inert soil all kinds of germs, it is easy to avoid the formation of root-nodules, and to prevent pea-plants from obtaining nitrogen from the air; while on "seeding" the soil with bacteria, by means of fresh loam-water, or by matter actually taken from a nodule, peas (and other leguminous plants) may be made to grow freely, and to accumulate much nitrogen from the air. Indeed, the growth of the peas — or other plants — is so vigorous that it is evident, even to the most superficial observation, that they can obtain from the air, in this way, all the nitrogen they need.

It should be clearly understood that these experiments do not teach that peas or clover, or any other agricultural plants, can assimilate free nitrogen from the air by their own unaided efforts. It is only through the intervention of microscopic organisms which live upon the roots of the pea-plant, or the like, that the free nitrogen can be put to use.

Beside peas, it was found by Hellriegel that vetches and horse-beans could readily be supplied with nitrogen from the air by seeding the sand of the experimental pots with the bacteria which live in ordinary loams; while he proved that young plants of barley, oats, turnips, mustard, sugar-beets, and buckwheat, growing in non-nitrogeneous sand, derive no benefit whatsoever from additions of the loam-water, but remain in a starved condition.

It is to be remarked that, for "seeding" the pea-roots, Hellriegel leached a quantity of rich loam with water, and, after allowing the turbid liquid to settle somewhat, added a very small quantity of the cloudy water to the sand in the pots. In each instance, the quantity of liquid used was extremely small, and no more than a faint trace of nitrogen was contained in it, so that the pea-plants could not possibly have got any direct good from this nitrogen.

Direct Inoculation with the Bacterium.

More recent investigators have discarded the loam-water altogether, and have inoculated the pea-roots, either with matter taken directly from root-nodules upon the point of a needle, or with the pure root-bacterium itself, uncontaminated with other organisms, as obtained by "cultivating," in appropriate media, some of the matter taken from root-nodules. By operating in this way, Prazmowski has seen that young pea-plants suffer at the moment of inoculation, because, in the beginning, the development of the colonies of bacteria, and of the nodules which enclose them, is at the expense of the store of nutriment in the seed, which would otherwise be wholly devoted to the nourishment of the young plant. But this temporary distress is speedily overcome as soon as the plant begins to feed upon the substance of the bacteria, and thenceforth the inoculated plants grow much better than those not inoculated.

It is evident that the root-bacteria take free nitrogen from the air and transform it into organic compounds, and that the pea-plant puts these nitrogenous matters to use either immediately or after the bacteria have died, or after they have undergone certain changes which are not yet clearly understood. Whatever the details of the process of translocation may be, it has been conclusively proved that nitrogenous matters do actually pass in some way from the nodules into the plant. Loew has suggested that, by cell-action in the bacterium, free nitrogen may perhaps be converted into ammonium nitrite: —

$$N_2 + 2\,H_2O = NH_4\,NO_2.$$

Root-bacteria help all Leguminous Plants.

Beside peas, beans, and vetches, several other kinds of leguminous plants — notably lupines and serradella (Ornithopus sativus), — can be supplied with nitrogen from the air by the action of bacteria in the soil. But it seemed to Hellriegel that each kind of plant needed to be acted upon by its own special bacterium, and to be dependent on the growth of its own peculiar root-nodule. He argued that some varieties of these useful bacteria are much more rare than others. It has long been known, for that matter, that the nodules on the roots of lupines differ materially from those of peas, both in appearance and as to their position upon the roots. In order that his experiments with lupines and serradella should succeed, Hellriegel found it necessary to prepare the loam-water from sandy soils that had been taken from fields and regions where these crops are habitually grown. Neither of these plants got any good from loam-water obtained from rich loams such as had been found to be excellent for peas, beans, and vetches; but on seeding the sand with loam-water of the right sort, Hellriegel repeatedly grew lupine-plants which weighed 45 times as much as those which got no loam-water. He found, moreover, that these vigorous plants contained 80 times as much nitrogen as the starvelings, — all of it taken from the air. Prazmowski also got no good on inoculating lupine-roots with pure bacteria of the kind which form nodules on peas, and Nobbe, in his turn, found that each kind of legume seemed to require its own special bacterium. He urges that the lupine bacterium is rare in regions where lupines are not grown as a field crop, while it abounds in localities where lupines are habitually cultivated.

As regards red clover, it is still uncertain what kinds of loams are best suited to supply bacteria for its support. That some kinds of loam will probably be found better than others for this purpose is indicated by the practical experience of farmers who see daily that red clover grows readily on some soils, and fails to grow upon others which, to all appearance, are not lacking as to fertility. I have myself seen red clover grow with remarkable luxuriance, during several successive years, in mere gravel at the middle of an old unused roadway, at a point where the wash from the higher parts of the road had some small opportunity to settle. So, too, Schindler has grown leguminous plants in soils poor in nitrogen, and found larger and more numerous nodules upon the roots than were found on the roots of plants grown in earth taken from a compost heap.

The following table shows what large quantities of nitrogen may be taken from the air by means of the bacteria proper to lupines, when the latter are grown in sand that contains no nitrogen: —

Without addition of Loam-water.			With addition of Loam-water.		
Hellriegel's No. of the Experiment.	Weight of Dry Crop. Grm.	Nitrogen in Crop. Grm.	Hellriegel's No. of the Experiment.	Weight of Dry Crop. Grm.	Nitrogen in Crop. Grm.
285	0.919	0.015	287	44.718	1.141
286	0.800	0.014	288	45.611	1.153
289	0.921	0.013	291	44.481	1.185
290	1.021	0.013	292	42.451	1.307

Even in the case of plants that had been fertilized with nitrate of lime, it appeared that much more nitrogen was harvested in the crops than had been added to the soil in the fertilizer.

Suggestions vouchsafed to Early Investigators.

It is to be remarked that from the earliest times farmers have recognized the fact that leguminous crops, far from exhausting the land, as grain crops do, actually tend to increase the fertility of the soil. It is withal a fact of no little historical interest that during a long term of years the observation had been made repeatedly by scientific men that leguminous plants may sometimes be grown with success in pots of mere sand, wholly devoid of organic matter and nitrogen compounds, though charged with ash-ingredients. Even Berzelius is said to have remarked upon this anomaly. Mulder illustrated it, and Boussingault, in his turn, was puzzled by it more than half a century ago. He proved, among other things, that in the ordinary farm practice of his country (Alsatia), there was carried off in the totality of the crops grown in a judicious course of rotation of grain and legumes, a larger quantity of nitrogen than had been put upon the land in the form of manure. As long ago as 1863, Hellriegel wrote as follows concerning the results of some experiments made at that time by himself: "Clover-plants may develop normally and completely in mere sand to which the necessary mineral constituents of plant-food have been added, in assimilable forms, even when this soil contains no trace of any compound of nitrogen or of organic matter." (Hoffmann's "Jahresbericht," 1863–64, vi. pp. 97, 98.)

In this country the phenomenon now in question has been conspicuously illustrated by Professor Atwater. But the results of all these observers were irregular, and, so to say, capricious to the last degree; and no one of the investigators was able to control his experiments. It is now known, of course, that these varying results must have depended on the presence or the absence of the micro-organisms, which may sometimes have been attached to one or another of the seeds that were sown, or may have fallen upon the soil from the air. Hellriegel has said, for example, of his own experiments made with peas and clover in 1862 and the following years, that the results were to all appearance so conflicting that he purposely abstained from publishing any detailed account of them in the hope that further study might give him some clew to the riddle. It was not until the idea had been broached that the power of leguminous plants to absorb nitrogen from the air may depend upon the presence of microscopic organisms attached to their roots, that any one had in the least degree comprehended why the results of the earlier experiments were so uncertain and occasional.

Experiments of Wolff and Kreuzhage.

Wolff and Kreuzhage, in particular, had carried out an extended series of experiments of this kind during several years, and their results now afford striking confirmation of the justice of Hellriegel's view. In the coarse calcareous river-sand employed by these investigators, excellent crops of lupines, horse-beans, clover, peas, vetches, serradella, etc., were grown when no nitrogenous fertilizer whatsoever had been added to the sand. On mixing ash-ingredients with the sand, much larger crops were obtained than could be got from the sand alone; but no advantage as to increase of crop, or only a very slight advantage, was gained by adding nitrate of potash to the sand to reinforce the ash-ingredients. Moreover, on analyzing the crops, and comparing the nitrogen in them with that contained in the seeds sown and the fertilizers employed, it appeared that the leguminous plants had really collected large quantities of nitrogen from the air. The significance of these results, and the difference between the behavior of leguminous plants and of cereals towards nitrates, will appear from the following table, which gives the mean amounts of dry total crop obtained in 9 series of experiments with oats, and 28 series of experiments with clovers and pulse: —

	Oat Crop.		Pulse and Clover Crops.	
	Grm.	Per Cent.	Grm.	Per Cent.
Mere sand	26.62	100	50.52	100
Ash-ingredients . . .	28.60	107	119.53	237
Little nitrate	71.62	269	112.52	223
Much nitrate	115.50	584	122.29	242

The following table gives the weights in kilo. of nitrogen accumulated in the leaves, stems, and seeds, but not in the roots and stubble, of the several crops enumerated, calculated as if grown on a hectare of land: —

	Horse-beans.	Lupines.	Red Clover.	Peas.
No manure	57.7	88.3	135.8	84.7
Ash-ingredients . . .	146.2	359.3	334.1	464.9
Little nitrate	54.6	158.8	318.8	643.5
Much nitrate	89.5	195.8	242.9	668.1

Some of the experiments of Lawes and Gilbert clearly illustrate the fact of the increase of nitrogen in the soil in which red clover is grown. Thus a field on which 6 successive crops of wheat, oats and barley had been grown with artificial manures was divided, and one-half of the land was sown with red clover and the other half with barley, both unmanured. After good crops of clover-hay and of barley had been harvested, the soil was analyzed, with the result that 0.1566 % of nitrogen was found in the first 9 inches of the clover-soil, and 0.1416 % in the barley-soil. The increase of fertility was likewise very remarkable, for in the following year the unmanured barley on the clover-land yielded 58 bushels, while that on the other half of the field which followed barley yielded less than 33 bushels to the acre.

Views of Practical Farmers.

Another point of historical interest is that several of the most accurate observers among practical agriculturists have always held that leguminous crops do, in some way, bring nitrogen to the land from the air. Men like Thaer and Walz were aware of the fact, and nothing could be more explicit than Gasparin's descriptions of it. In his classical "Cours d'Agriculture," he constantly calls attention to the nitrogen-bringing power of leguminous plants, and in one of the volumes of that work 70 consecutive pages are devoted to descriptions of the plants which compose the "Groupe Améliorante."

The experiments of Lawes and Gilbert on the fertilization of grass-land also showed very clearly that applications of potash salts together with other mineral fertilizers (without any nitrogen) greatly increased the growth of leguminous plants and very much increased the quantity of nitrogen that was carried off from the land in the crops. The amount of nitrogen taken up by the hay-crop thus manured amounted to 1.67 times as much as was taken up by the hay grown on unmanured land, and to nearly 3 times as much as was got by applying the same kind of manure to wheat and barley on arable land.

Confirmation of Boussingault's Dictum.

One noteworthy experiment of Hellriegel was his repetition of the famous old experiment of Boussingault, who put calcined soils into large glass carboys, and sowed in this non-nitrogenous earth various kinds of seeds. Finally, he determined, by analysis of the dwarf plants which sprung from the seeds, that no nitrogen had been taken from the air. Now, Hellriegel repeated this classical experiment with the simple variation that he added to the calcined earth in the carboy a drop or two of loam-water, such as has been described. Thanks to this addition, he had no trouble in growing vigorous pea-plants which contained an abundance of nitrogen taken from the air. Oats and buckwheat, on the contrary, starved through lack of nitrogen, in spite of the addition of loam-water.

Can the Legume-bacteria use Humus?

Beside the fungi which live in or upon roots, there are other microscopic organisms living in the soil itself which are capable of fixing free nitrogen from the air, as will be explained directly. It has been proved that these non-parasitic organisms obtain a part of their nourishment from the humus of the soil, either directly or perhaps from carbonic acid which has been formed through oxidation of the humus. But, as regards the symbiotic fungi, it is not yet known what influence may be exerted by the humus in ordinary soils, either for supplying nitrogen directly to the legume-bacterium, or for providing this organism with carbonaceous food so that it may perhaps be better able to take nitrogen from the air. It will be noticed that in the foregoing experiments with leguminous plants, the question whether or not the root-bacterium can take any nitrogenous food from the humus of the soil has been wholly excluded. For the sake of scientific precision, the experiments were made in pure sand, wholly free from organic matter.

As will be explained in the next chapter, there is some evidence that several broad-leaved plants — clover among others — may perhaps be helped by manures that are rich in organic matters, and it is not improbable that some kinds of root-fungi may be the means of utilizing the organic matter. On the other hand, it is not wholly inconceivable, as regards some kinds of leguminous plants, — such as the lupine, for example, — that the presence of humus in the soil might do harm by fostering the growth of micro-organisms which are inimical to those which cause nodules to form upon roots; while, on the other hand, the question obtrudes itself whether the well-known general utility of vegetable mould and the superiority of farmyard manure over mixed artificial fertilizers may not depend upon the power of certain root-fungi to take nitrogen from humus in the soil and transfer it to some kinds of crops.

It would seem, in any event, that the old problem, What value, for the use of farm-crops, has organic nitrogen in its various forms? will need to be studied anew in connection with another question, — viz., Which of the several nitrogenous organic matters used as manures are best fitted for feeding parasitic-fungi that live upon the roots of plants? It is known in a general way that most fungi can and do feed directly upon some kinds of organic nitrogen; but many experiments and observations will have to be made in order to determine precisely what kinds of organic matter are best suited for this purpose. There is an old experiment by Gazzeri which may have some bearing upon this point. He mixed a quantity of hoof-meal with loam, charged two vessels with the mixture, and grew beans in one of them, while in the other nothing was planted. Both the samples of earth were treated alike until the beans had been harvested, when none of the meal could be found in the earth where beans had grown, though a considerable quantity was still left undecomposed in the fallow earth.

As regards the fungi on the roots of forest-trees, the first thought was that they must take nitrogen from the humus which surrounds them; but in the light of the more accurate observations which have been made on the leguminous plants, it may well be asked whether the woodland fungus does not take nitrogen from the air rather than from vegetable mould. The well-known fact that the humus left when a forest is cleared is useful as a fertilizer, is readily explained on the assumption that the fungi on tree-roots take nitrogen from the air, as the fungi on clover roots do. Many years ago, Chevandier called attention to the large amount of nitrogen which is accumulated every year by the trees in a forest, and it is now familiarly known that the twigs and young leaves of trees are highly nitrogenous; but before the discovery of the phenomena of symbiosis it was not easy to conceive how, or from what sources, all this nitrogen in the trees had been obtained.

Moreover, if any of the root-fungi do really take nitrogen from humus, it will follow that a mere chemical analysis of a soil may convey little or no information as to the capacity of that soil to bear crops, so long as we are ignorant as to what kinds of humus are best suited for the support of the fungus.

Rotations Elucidated.

Whatever may hereafter be discovered in respect to these questions, it is none the less true to-day that a flood of light has already been thrown upon the subject of the rotation of crops; for the action of the root-bacteria serves to explain how it is that certain plants, such as clover, lucern, sainfoin, and lupines, which are themselves supplied with nitrogen by means of the bacteria, can charge the soil with useful nitrogen for the benefit of a succeeding crop. It is now evident enough that the roots left in the ground when a leguminous crop is harvested, must be equivalent to a considerable dressing of manure, because of the nitrogenous nodules upon these roots.

It has long been known empirically that large quantities of nitrogen do accumulate in the abundant roots and stubble of clover and lupines, and that this nitrogen is left in the soil in a condition fit for the use of succeeding crops. It was recognized almost from the first, that the power to maintain rotations of mixed crops during terms of 4 or 5 years on the basis of one single dressing of manure, applied at the beginning of the course, must depend on nitrogen accumulated in some way by the leguminous crop. It is the explanation of the fact which is new to us. Until this knowledge had been gained, neither the universality of the fact nor its supreme importance could be comprehended fully.

As Dehérain has shown, the amount of nitrogen in the soil of fields where sainfoin or lucern is grown continuously during several years may increase to such an extent that the gain admits of being exhibited by analysis; and Schultz has insisted strongly and repeatedly that on the poor sandy soil of his farm in North Germany, certain crops — notably lupines, clover, peas, serradella, and vetches — act as "collectors of nitrogen," and leave more nitrogen in the soil, for the use of succeeding crops, when allowed to ripen, than they do when mown green. So, too, European farmers are accustomed to see wheat succeed better after clover and after horse-beans, than after a bare fallow, in spite of the familiar fact that a great deal of nitrogen and of ash-ingredients are carried off from the land in these preparatory crops, and especially by the clover. There can indeed be little doubt that the growing of legumes as a preparation for the growing of grain dates from a very early period. Thus, on the island of St. Michael, one of "the Azores, where primitive customs are maintained to an extraordinary degree," the English naturalist Moseley noticed, in 1873, "a kind of lupine planted in geometrical patterns amongst the wheat, to be ploughed in after the crop was reaped, as manure."

As a matter of course, the amount of nitrogen in a soil will be largely increased when the whole of a leguminous crop is ploughed into it, as in this case; and it is equally evident that the stock of nitrogen in the soil could not be increased to the same extent if the leguminous crop were to be harvested and only the roots and stubble were ploughed under.

Soil-nitrogen may Decrease when Legume-crops are taken from the Land.

There are in fact irreproachable experiments which show that in some cases the store of nitrogen in the soil may diminish when crops of clover, or the like, are continually taken away from the land while no nitrogenous manure is added to it. Thus Lawes and Gilbert found that there was a very large diminution in the percentage of nitrogen in the soil of an old garden from which luxuriant crops of red clover had been taken year after year. On comparing samples of earth taken in the 4th and the 26th year of the experiment, it appeared that the diminution of nitrogen in the uppermost 9 inches of soil represented three-fourths of the amount which had been contained in the clover crops of the intervening period, and the indications were that there had been a considerable reduction in the lower layers of soil also; though it is to be presumed of course that nitrogen may have been lost from the land in other ways than by the crop alone.

So, too, the soil on which beans had been grown continuously exhibited no gain in nitrogen; and in their experiments on the mixed herbage of grass-land, the soil of a field, which, under the influence of potassic and other mineral fertilizers, yielded large quantities of leguminous herbage rich in nitrogen, was found, after 20 years, to contain a considerably lower percentage of nitrogen than any other piece of land in the whole series of experiments. In like manner, Prove found, in experiments made with lupines, beans and mixtures of clover and grass, that the quantity of nitrogen in the soil was reduced — although much more slowly than was the case with maize, rye and buckwheat — when the crops were taken away from the land. He urges, that in ordinary farm practice, when they are not ploughed under as green manure, the leguminous crops should be regarded as hindering the waste of nitrogen from the soil rather than as a means of increasing the stock of the soil-nitrogen.

But it is to be remarked that even if the amount of total nitrogen in the soil is less after the removal of a leguminous crop than it was before that crop was grown, it will still be true, generally speaking, that a part at least of the nitrogen left by the roots in the soil will be of such superior quality that the succeeding crops may get much more benefit from it than could have been derived from the normal, inert soil-nitrogen.

Legumes can use Nitrates.

The facts that much nitrogen should accumulate in the soils where leguminous crops are grown; that these crops should often be benefited by applications of merely mineral fertilizers, such as potash-salts; and, strangest of all, that these crops should, in field-practice, gain comparatively little advantage from applications of active nitrogenous fertilizers,—have often been remarked upon, and have seemed all the more extraordinary in view of the well-established truth that peas and beans, and various kinds of clovers, do assimilate nitrates from the soil in considerable quantity, and that nitrate of soda is a useful manure for these crops. It was observed by Lawes and Gilbert — on examining, in summer or early autumn, the soils of fields which had received no nitrogenous manure, but from which crops of various kinds had recently been harvested — that where leguminous plants had grown, much smaller quantities of nitrates were to be found in the soil than where the land had lain fallow and there had been no plants to consume the nitrates. On the fallow land, from 40 to 60 lb. of nitrate-nitrogen to the acre were detected in the upper 27 inches of soil, while on fields which had borne red clover, white clover, Bokhara clover, lucern, or vetches, not more than 5 to 14 lb. of nitrate-nitrogen were found in this depth of soil, and much the larger part of these quantities were in the uppermost 9 inches of earth. It was remarked that, inasmuch as active nitrification is always in progress at the surface, it requires a very energetic and continuous assimilation of nitrates by the crops to reduce the nitrate-nitrogen to so small an amount. Below the surface-soil, nitrates were practically absent to a very considerable depth, especially where the deeper-rooted kinds of leguminous crops had grown.

Hellriegel, in experiments made many years since, found that clover can take nitrate-nitrogen from the soil, and be nourished by it; and his more recent experiments show clearly that leguminous plants can and do feed upon nitrates on occasion. He recommends that, on poor land, light dressings of nitrogenous fertilizers should be applied, since they will serve to nourish the young plant until the time when nodules have formed upon it. For this purpose, nitrate of ammonia is said to be particularly useful. (Wilfarth.) It was noticed, however, that the economic effect produced by a given weight of a nitrate applied to leguminous plants was less than that produced upon the cereal grains. Thus, where one part of nitrate-nitrogen applied to oats or barley gave an increase of 90 to 100 parts of dry matter, the increase of dry matter under like conditions amounted to no more than some 50 or 60 parts in the case of serradella.

It was found that peas, and most other leguminous plants, grow well enough from the first in sterilized soils to which nitrates have been added, — though, in this case, the amount of nitrogen found in the crop is always less than that contained in the quantity of nitrate which was applied to the soil; while in sterilized soils devoid of nitrates, the plants speedily starve from lack of nitrogen, until such time as the necessary bacterium has been added to the soil, and has had opportunity to develop. Practically, it will usually be advisable in field culture to apply light dressings of easily assimilable nitrogenous fertilizers to leguminous crops, in order to help forward the young plants. As Prove has insisted, peas in particular respond freely to applications of nitrate of soda or nitrate of lime. By employing either of these fertilizers, a heavier crop may be got in a shorter time than can be grown without them. It is seldom that a maximum crop can be obtained in the absence of nitrates, because in that case the growth of the plant is apt to be very uneven; some particular plants may grow freely, while others are seen to be suffering for food.

The Utility of Nitrates for Leguminous Crops is commonly Subordinate to that of the Root-Bacterium.

Ordinarily it happens, even when nitrates are present in the soil, that more nitrogen will be found in a leguminous crop at the time of harvest than the limited amount of nitrate could possibly have supplied. So, too, in the experiments of Lawes and Gilbert, it appeared that the amounts of nitrates which were actually formed in the soils of their fields were not sufficient to account for all the nitrogen which was found in their leguminous crops, — that is to say, the amounts of nitrates actually observed to exist in the soils were not large enough to account for the whole of the nitrogen carried off the land in the clover crops. To quote their own words: —

> " A good crop of red clover may, on land in favorable condition, but without the direct application of manure, yield, from seed sown in the spring of the previous year, hay containing 200 lbs. of nitrogen per acre, and also leave much nitrogenous crop-residue in the surface soil. Bokhara clover, grown in a soil on which red clover had frequently failed, yielded during 5 successive years, without any application of nitrogenous manure, an average of about 93 lb. of nitrogen per acre per annum. These quantities much exceed the amounts which, according to our present knowledge, can be furnished by nitrates in the soil. . . The question obviously arises, whether leguminous plants do not find in soils suited to their growth some other source of nitrogen than nitrates. The very large amount of nitrogen taken up by these crops would, on this supposition, be due to their possession of a power of utilizing nitrogen existing in the soil in a con-

dition of combination, as well as of distribution, not available to cereal crops."

In soils rich in available nitrogen the roots of leguminous plants are apt to have comparatively few nodules. Sometimes there are hardly any nodules at all, and it would seem to be evident in such cases that the crop must take much less nitrogen from the air than it would have done if the soil-nitrogen had been less abundant. It is to be said, however, that Gasparin, on comparing the quantities of manure employed in a number of instances in laying down fields to lucern in Southern France, observed that the crops were larger when more manure had been applied to the land, although the yield of forage was not proportional to the amount of manure. He said, "In the case of this plant, as in that of all the other plants which are called ameliorants, the manure acts only to nourish the shoots in their earliest youth, before the period when the plant has become developed so that it can get food from the air. In cultivating leguminous crops, it will be advantageous to push the dose of manure to the utmost limit, which will be the point at which we cease to get an adequate increase of crop."

It is evident from practical experience, that, on land dressed with farmyard-manure, leguminous plants ordinarily take a part of their nitrogenous food from the soil while another part comes from the air through the root-nodules. Hence the importance in many cases of growing these plants either on undunged fields or by means of artificial fertilizers, as has in fact long been customary in respect to gypsum.

It may even be urged, as has been done by Wilfarth that leguminous crops are out of their proper place when grown on land that has just been dunged, since they do not in that case act their legitimate part towards the support of the farm, and may then fairly enough be classed among exhaustive crops rather than as collectors of nitrogen. It is evident enough, however, from farm experience, that several leguminous crops can derive profit from applications of farmyard-manure. Thus, Gasparin has said of the ordinary edible bean: —

"While other leguminous crops appear to take a large part if not all their nitrogen from the air and not to exhaust the soil, but to leave behind them in their roots and stubble more of this element than they have taken from the land, the bean, like the cereal grains, draws its nitrogenous constituents from the soil, and consequently must be classed with the grain-crops in respect to the quantity of manure which should be applied to it. Of horse-beans, he says, "In general, a crop of horse-beans can bear, without lodging, all the manure one may care to put upon the land, while there is left in the roots and stubble more nitrogen than has been carried away in the vines and seeds." He says, furthermore, "In the cultivation of peas some difficulties are encountered which do not appear in the growing of beans. Beans will bear very well a complete manuring which causes them to grow freely when they are young, while, later on, the action of the leaves takes the place so to say of that of the roots, and the plants appear to be nourished at the expense of the air. Peas on the contrary may continue to be fed through their roots after the sprouting of the leaves and there may thus be formed a superabundance of herbage which may continue to grow at the expense of the flowers and fruit, so that sometimes the flowers may be stifled and fail to appear altogether. No considerable harvest of peas can be got by means of heavy manurings which may sometimes lead to the production of nothing but vines and leaves." He noticed that lucern derived no little advantage from abundant manurings.

A practical Application of Hellriegel's Teachings.

The correctness of Hellriegel's conclusions as to the symbiotic action of bacteria on the roots of legumes has been strikingly illustrated in actual farm-practice by experiments made upon a very large scale with peas and horse-beans, first by Salfeld in North Germany, and afterward by many other persons. Salfeld's experiments were made on recently reclaimed moorland which had been limed and dressed with phosphatic slag, with kainit, and with nitrate of soda; and it was found that the crops of peas and beans were largely increased on all those parcels of land which had received — in addition to the artificial fertilizers — small quantities of fertile loams brought from distant fields which were known to yield good bean-crops. Salfeld remarks that the surprising effects produced by the fertile loams could be attributed neither to their physical condition nor to their chemical composition. The amount of plant-food contained in these loams was insignificant in comparison with that added in the fertilizers, and that naturally contained in the soil proper. He was forced to the conviction that Hellriegel's teachings are of general applicability, and that the fertile loams employed in his own experiments really contained microscopic organisms which enabled the peas and the bean-plants to get nitrogen from the air. Inoculation is specially to be recommended when lupines (or other new kinds of leguminous plants) are to be introduced into regions where such plants have not been grown before. Also in cases where any leguminous crop is found to be but scantily supplied with root-nodules, as may happen on land that has just been cleared.

It is evident, however, that any land "inoculated" in this way must be fit for the bacteria to live in, in order that profit may be got from the operation, — that is to say, the soil must be in such condition and of such composition that no hinderances shall be offered to the increase of the root-bacterium. Thus, Schmitter spread earth from lupine fields upon worn out heavy loam, and sowed lupines upon the land, but got no good by so doing; and it was evident from the behavior of the crop during the first months of the experiment that the soil was not at that time in a fit condition for lupine growing. On fertile land, rich in available nitrogen, inoculation might not produce much effect simply because the crops could grow there without help from the nodule bacteria. (Wilfarth.)

Nobbe and others have noticed that the root-bacterium may not spread very rapidly from one part of the soil to another. Thus, in the case of pea-plants standing in sterilized soil, when loam-water was applied to particular parts of the roots, at depths, viz., of 120 and of 200 mm. from the surface of the earth, nodules grew only at the infected places. So, too, when some loam-water was put upon the surface of the sterilized soil, and some at a depth of 120 mm., nodules grew on the roots only near the surface, and at the depth of 120 mm., while the roots between these limits remained free from nodules. It appeared that the roots of plants of any age could readily be inoculated by means of the loam-water, provided it was applied to young root-fibres beset with hairs. It follows, of course, that when loam charged with symbiotic fungi has been strewn upon a field for the purpose of inoculating it, pains should be taken to harrow in this loam pretty thoroughly.

Leguminous Crops are Capricious.

Yet another matter which has greatly puzzled the farmers is the familiar fact that some kinds of leguminous plants can seldom be grown continuously on one and the same piece of land for any great length of time, no matter how fertile this land may be, or how abundantly it may be supplied artificially with plant-food. As Evelyn said, in his day, "Peas [and clover] degenerate betimes, at least in 2 or 3 years, be the land never so good." The suggestions lie near at hand that enemies of the micro-organism may accumulate in the soil to overwhelm it, or that the secretions of the bacterium itself may finally destroy it, or that poisonous chemical substances which result from reactions incidental to the life of the bacterium, may eventually accumulate to such an extent as to destroy it or to destroy the clover. It is highly probable, indeed, that matters hurtful or poisonous to the root-bacteria are secreted by them, or produced in some way as a result of their activity, — in the same way that the highly poisonous alkaloids, known as ptomaines and toxines, are formed by the action of micro-organisms in the bodies of animals suffering from certain diseases, as well as upon dead animal matter, such as meat or milk, during decay. It is possible, moreover, though not very probable, that the bacteria of the nodules may use up some kinds of nitrogenous matter in the humus of the soil, and that this action may explain how it is that on land which has just borne clover or peas, several years must usually be allowed to pass by before these crops can again be grown with success.

When this subject has been adequately studied, experimenters may perhaps be able to determine why it is that wheat sometimes fails to grow well after peas and vetches; and they may even discover how it is that wheat, as a general rule, does not yield particularly good crops when grown after potatoes or after barley. Liebscher found, on growing peas continuously, that the roots were beset with nematode worms, while peas grown in rotation remained healthy. After some years of incessant pea-growing, the plants failed utterly unless dressed with nitrogenous fertilizers, and even then they were miserable, and had few or no nodules, though nodules were abundant on the roots of peas grown close by in rotation. The roots of the sickly pea-plants were found to be covered with nematode worms, and so were the roots of an oat-crop which was grown after the peas, while no nematodes could be detected on any of the plants on adjacent plots. Liebscher urges that wherever leguminous plants are apt to fail, the farmer will do well to observe whether nodules may not be absent from the roots and nematodes present. The too frequent growing of legumes, he says, far from breeding the nitrogen-bringing bacterium, may perhaps do the land harm by filling it with pernicious nematodes.

Merit of Clover Rotations.

The propriety of basing farms, when possible, on clover rotations, and, in general, the advantages of cropping land in such manner that the inert nitrogen of the air — to say nothing of that in humus and farmyard-manure — shall be put to legitimate use, have become plainer than ever since the doctrine of symbiosis has been formulated. For example, Walz has described special instances of soils naturally fertile, which, when worked on the old plan of growing two grain-crops in succession, and leaving the land fallow every third year, could be made to yield tolerably good crops of grain during long terms of years, without applying any manure, provided the land was occasionally "brought into condition" by seeding it down to lucern. Of itself, the regularly recurring bare fallow of the third year was insufficient to keep up the land to the normal pitch of productiveness; and the grain-crops were seen gradually to diminish until the moment when lucern was interpolated after the third or fourth recurrence of the fallow year. When the land was again ploughed, after having been kept in lucern during several years, it was found to be recuperated, and fit to bear new courses of grain-crops, in spite of the fact that much larger quantities of nitrogen and of ash-ingredients had been removed in the successive cuttings of lucern than could have been carried off during the same period of time in case grain had been grown upon the land instead of the lucern. The inference is, that, thanks to the action of the fungus, large quantities of useful nitrogen-compounds were left in the land, in the roots of the lucern. Several of the experiments of Lawes and Gilbert clearly exhibit the increased fertility which results from the growth of horse-beans or red clover. It frequently happened that the grain-crops taken after beans or clover were equal to or even larger than similar crops grown in the same season after a bare fallow.

How Lupines improve Sands.

The continuous growth of lupines on poor, sandy land in Germany, affords a striking illustration of the great practical importance of the fixation of nitrogen by the root-bacterium. Thus, on applying each year 3 Centner of kainit to the Morgen of land, without any other fertilizer, — except an occasional dressing of plain superphosphate, which never did any visible good,— Schultz grew lupines, during 15 years, at the rate of at least 6 Centner seeds and 12 cent. straw. He reckons that these crops carried off from the hectare 1,357 kilo. nitrogen, 344 kilo. phosphoric acid, and 482 kilo. potash. At the close of the experiment, analysis showed that the soil, taken to a depth of two feet, contained 3,851 kilo. nitrogen to the hectare, while the soils of contiguous fields which had been pastured, or cropped in a different way, and which had received more or less dung, contained respectively no more than 1,580 and 2,004 kilo. of nitrogen. All of which — as well as the continuous crops of lupines — went to show that very considerable amounts of nitrogen had accumulated in the lupine land.

Some Mosses and Algae can fix Nitrogen.

There is still much to be learned as to what kinds of plants are capable of being supplied with nitrogen from the air, though doubtless there are many such beside the leguminosae. The roots of the common flowering nasturtium (Tropeolum), for example, are seen sometimes to be thickly beset with nodules, and the presence of these excresences is coincident with vigorous growth of the leafy parts of the plant; a fact which may serve to explain why it is that in some instances potted nasturtiums fail to grow well, in spite of careful tending, while in other cases they thrive extremely under what had seemed to be similar conditions. It has been proved, moreover, that, beside fungi proper and those plants which support or contain nitrogen-bringing micro-organisms (as legumes and lichens do), there are some species of the lower orders of green plants, such as certain algae and mosses, which have the power of fixing free nitrogen. (Schloesing and Laurent.)

Healing of the Stumps of Conifers.

In the light of what has already been learned as to the power of fungi attached to roots, to supply these roots with food, it becomes possible to offer a credible explanation of a curious phenomenon which has long excited the interest of foresters. On cutting down young coniferous trees, it has repeatedly been noticed in Europe that the stumps sometimes heal and become covered with bark, much in the same way that scars on the trunks of living deciduous trees become covered where boughs have been lopped off. It has been observed that these coniferous stumps sometimes remain alive during many years, and continue to produce annual circles of new wood for an indefinite period, although no leaves, branches, or suckers are connected with the stump. This observation has been made more particularly in respect to stumps of the silver fir of Europe, and to those of the European pine; but the phenomenon has sometimes been noticed on stumps of the larch, the Scotch fir, and the spruce fir; and several observers have specified that the stumps seen by them were growing on deep peat or in bog-earth.

It has sometimes been suggested that the roots of such stumps may have by some accident become engrafted (underground) upon, or fused with, the roots of neighboring living trees, from which sap may flow to support the bare stump; but this idea has never been generally accepted, for the good and sufficient reason that it is commonly contradicted by the circumstances under which the stumps are situated. It is much more reasonable to suppose that fungi, which had become established upon the roots when the tree itself was living, may continue to contribute food for the support of the stump, even after the tree has been felled.

The Line of Least Resistance.

It may be said, in conclusion, that the matter of blended growth is really less remarkable than might appear at first sight. It may be regarded, indeed, as affording a striking illustration of the truth of the famous dictum of Stephenson, that "Where combination is possible, competition fails"; and as being in complete harmony with the familiar principle of Least Action (or of Minimum Effort), which was at one time much debated by philosophers.

Fixation of Nitrogen by Fungi in General.

Beside the symbiotic organisms, as above described, it is very evident that many other kinds of fungi must have the power of assimilating free nitrogen from the air. The necessity of accepting this view in order to comprehend certain familiar appearances connected with the growth of fungi has long been manifest. The rapidity of the growth of many species, as well as their appearance on bare rocks and on other inert materials such as are wholly incapable of supplying any other form of nitrogenous food, has always pointed directly to this conclusion. Great lichens, such as the reindeer moss, are seen to grow freely on bare rocks and on soils so sterile that no ordinary plants or weeds can live upon them, and there are instances on record where fungoid growths have covered the surfaces of iron articles in the course of a day or two after the iron had been cast.

The following citation from Trommer's "Bodenkunde," 1857, pp. 456–458, will serve to illustrate a feeling which prevailed before the actual discovery, in more recent years, that many cryptogamic plants do really possess a power of fixing nitrogen. "The occurrence of certain fungi on the most sterile sands, where no other crop than pine-trees could possibly be grown, is a fact worthy of special attention. While the origin of fungi is in any event to be classed among standing problems in physiology, the appearance of those kinds which grow on mere sand is problematical in the highest degree, for they not only appear upon soils which are wellnigh completely free from organic matters, but they develop with extreme rapidity and they produce great quantities of organic matter such as are not to be observed in the case of any phanerogamic plant. These appearances become even more remarkable when account is taken of the large quantity of nitrogen which the fungi actually contain, and when we reflect on the poverty, as to nitrogenous constituents, of the soils on which the fungi have grown. I have never been able to detect in such soils enough nitrogen to be of any consequence. . . To my own mind the facts and the appearances remain a physiological problem, as was just now said."

Berthelot's Bacteria.

This matter first received definite explanation through the experiments of Berthelot, which showed conclusively that certain microscopic organisms living in the soil can and do feed upon the free nitrogen of the air. Berthelot noticed, in the first place, that in clayey and sandy soils, as well as in loams generally, there is during the growing season a slow but incessant fixation of free nitrogen from the air due to the presence of microscopic organisms in the soil, which feed upon the humus or other organic matter therein contained, and also upon the free nitrogen of the air.

This fixation of nitrogen, dependent upon micro-organisms, occurs both in daylight and in darkness, though more freely in the light; best at summer temperatures between 50° and 104° F. and where there is a good supply of oxygen, for the organisms are aerobic. But it is not desirable that the conditions should be favorable for active nitrification. The process is immediately put an end to on heating the soil to 230° F., so as to destroy the organisms; and it does not occur in the winter. A high degree of porosity in the soil is favorable for the fixation of nitrogen. More nitrogen is fixed in case the soil is freely exposed to rain than when it is protected. A proportion of water in the soil not exceeding 12 to 15 %, and not falling below 2 or 3 % is favorable. Fixation occurs not only in bare land, but also in soils upon which plants are growing, though less nitrogen accumulates in this way in soils covered with vegetation than in those which are bare, apparently because the plants take up and use some of the nitrogen which has been fixed. In some instances, however, it has been noticed that no fixation of nitrogen from the air occurred in soils taken from fields which had recently borne leguminous crops, perhaps because of the presence in these soils of micro-organisms inimical to those whose action Berthelot has studied.

The nitrogen thus gained from the air is at first in a form insoluble in water, but in most instances a notable proportion of the fixed nitrogen is soon converted into nitrates.

From Berthelot's laboratory experiments, it may be reckoned roughly that sands and clays might fix in a year as much nitrogen as would amount to 75 to 100 or more lb. to the acre of land. Indeed he noticed in two exceptional instances that nitrogen was fixed by sand at the rates of 525 lb. and 980 lb. to the acre. But as regards loams, at least, he found that the fixation of nitrogen from the air ceased as soon as a certain not very large proportion of this element had been accumulated, and it would appear that soils may sometimes be better able to fix nitrogen in proportion as they contain less humus. These experiments are manifestly of very great scientific importance, and they are doubly interesting in that they mark a decided step forward in a long series of observations which now serve to support them, or even to verify them.

The Observations of De Saussure and Mulder.

It was maintained long ago by several observers, among others by De Saussure, that, under certain conditions, a part of the nitrates which form when vegetable matters decay come from the free nitrogen of the air. Other observers urged that the large quantities of nitrates sometimes produced on chalk cliffs which contain but a trace of organic matter point to the truth of the conception that some of the nitrogen in these nitrates must have come from the air. Faraday observed that almost all solid substances exposed to the air contain more or less nitrogenous matter, and his observation has been repeatedly verified and illustrated. Mulder in his day urged with much force, that, when decaying humus undergoes oxidation by the action of air, some of its hydrogen unites with nitrogen from the air to form ammonia [or some other nitrogen compound]. He supported this view primarily upon experiments which showed that moulds grown upon non-nitrogenous substances always contain protein. Thus, on leaving for three months dilute aqueous solutions of sugar in stoppered bottles with a sevenfold volume of air, an abundance of mould grew, which, on being collected and subjected to dry distillation, gave off large quantities of ammonia. So, too, starch kept under water in a bottle that contained air soon fermented, and the fungus which it had nourished gave off ammonia on being distilled; and in like manner woody fibre, decaying with scanty access of air in the lower layers of a vegetable soil, appeared to form ammonia, in consequence, as was supposed, of a part of the hydrogen of the fibre entering into combination with nitrogen from the air, while another part combined with oxygen.

In other experiments, Mulder grew bean-plants in soils that consisted either of ulmic acid (made from pure sugar) or of charcoal, with which 1 % of ash-ingredients had been admixed, and which were watered with pure water. He found twice and thrice as much nitrogen in the bean-plants as was contained in bean-seeds similar to those which he had planted, though the results of these experiments, when viewed in the light of the better knowledge of to-day, would naturally be attributed to nitrogen-bringing bacteria upon the roots of the bean-plants, as described on a previous page. It is none the less true, however, that, in consequence of Mulder's experiments, an impression obtained currency many years ago that ammonia is generated when nascent hydrogen from decomposing organic matters comes in contact with the free nitrogen of the air. Indeed, it was taught at one time that nascent hydrogen from water that is undergoing decomposition by the action of metals, such as zinc or iron, which remove oxygen from it, could unite with free nitrogen to form ammonia. But this idea was disproved by the experiments of Will.

Early Observations on the Fixing of Nitrogen by Fungi.

In certain experiments of Boussingault (see "How Crops Feed," p. 259), the amount of nitrogen contained in garden-loam was found to increase slightly during the summer months, although at the very time the carbon in the soil was wasted to an appreciable extent by oxidation. But in soils which had been deprived of organic matter no appreciable accumulation of nitrogen occurred. In a set of experiments by Fittbogen, in which jars of moistened peat, admixed with carbonate of lime, carbonate of potash, or other chemical substances, were exposed to the air in a greenhouse during 4 months, it was noticed in every instance that a given weight of the peat contained somewhat more nitrogen at the close of the experiment than had been contained in the same weight of peat at the beginning; but it was thought that this increase in the percentage proportion of nitrogen might perhaps be due merely to the circumstance that the carbon in the peat had been dissipated by way of oxidation more rapidly than the nitrogen.

Experiments by Cloez, also, on nitrification ("How Crops Feed," p. 263), point to fixation of free nitrogen from the air by the materials upon which he operated. In some experiments where lupines, hemp and beans were grown in garden soil, Boussingault noticed distinct gains of nitrogen over and above the amount contained in the soil and seeds at the beginning of the experiment. Eugling also observed decided gains of nitrogen on growing soy beans, for two successive years, in jars of moor-earth that had been mixed with carbonate and phosphate of lime and sulphate of potash. In spite of the waste of carbonaceous matters by oxidation, there was found more nitrogen in the soil at the end of the experiment than at the beginning; and in addition to this it was observed that no inconsiderable quantity of nitrogen was carried off in the crops. All of which manifestly consists with the more recent experiments, described above, in which leguminous plants were found to gain nitrogen from the air.

Koenig and Kiesow, in their experiments on the prevention of loss of nitrogen during the decay of organic matters, noticed that, instead of losing nitrogen in the course of the experiments, the substances usually gained a little of this element, especially when gypsum and loam were present. But the amount of this increase was so small that it was attributed to errors inherent in the method of experimenting. In these experiments the materials were mixed with water to a pap, which became strongly alkaline through fermentation.

Armsby (American Journal of Science, 1874, VIII, 337) exposed decaying nitrogenous organic substances, that were "moist, but not coherent," to a current of air, and observed that usually small amounts of nitrogen were lost from them, except in those instances in which the organic matters had been made alkaline with potash. Here he noticed distinct gains of nitrogen. In Armsby's own words: "We must conclude that decaying organic substances, in the presence of caustic alkali, are able to fix free nitrogen without the gain being manifest as nitric acid or ammonia, and probably without the formation of these bodies." It is to be presumed, of course, that fermentations favorable for the fixation of nitrogen were promoted by the alkali, — potash in this case.

Birner, also, on adding various substances to a mixture of horse- and cow-dung, and leaving the materials at rest for half a year, in a place sheltered from sun and rain, found that the amount of nitrogen in the dung increased in several instances through fixation of nitrogen from the air. The largest increase of nitrogen occurred in mixtures which contained respectively 1 % of kainit and 1 % of sulphate of magnesia; and a somewhat smaller increase was noticed in the mixtures which contained 2.5 % of slaked lime and 10 % of peat-dust. Per contra, there were large losses of nitrogen from a mixture which contained 5 % of peat-dust (7.2 % loss), and from one that contained 1 % of carbonate of lime (9.78 % loss). There was a small loss of nitrogen from a mixture which contained 1.5 % of slaked lime, and a large loss (7 %) from one that contained 0.5 % of the lime. A mixture which contained 1 % of gypsum showed a slight loss of nitrogen.

It is to be inferred from these results that the increase of nitrogen occurred in those instances where the conditions happened to be favorable for the growth of the fixing ferment, and that there was a loss of nitrogen from the manure when the conditions were favorable for nitrification — as when carbonate of lime was present — or for putrefaction. One portion of the manure, which was purposely kept moist during the six months, in order that it might putrefy, lost 6.6 % of its nitrogen, while another portion, which was allowed to dry out, lost only 1 % of its nitrogen.

Experiments of Selmi and Dehérain.

Kellner, on allowing moistened soy-beans and milk to ferment slowly, found that there was no loss of nitrogen from these materials, but a small gain, though meal of dried fish similarly treated lost a little of its nitrogen. Simon was even led to conclude that humic acid can absorb nitrogen from the air and from pure nitrogen gas, with formation of ammonia, but his results have been disputed by Vogel and by Prevost. Meanwhile, it had been shown by the Italian chemist Selmi that moulds and other fungi, both visible and microscopic, evolve hydrogen, especially from those parts which are in the shade. Ordinarily, or, so to say, normally, most of the hydrogen produced by the larger fungi combines with oxygen from the air to form water. But at the same time a little ammonia [or other compound of nitrogen] is formed by the union of some of the nascent hydrogen with nitrogen from the air. Selmi argued at once that this fact is one of much agricultural importance.

Many years after Mulder, Dehérain, returning to his idea, mixed humus taken from old trees with a solution of carbonate of potash, and warmed the mixture in a closed flask that contained a mixture of oxygen and nitrogen. He found that, while all the oxygen went into combination with the organic matters, an appreciable quantity of nitrogen also was absorbed. Whence he argued, that organic matters decaying in the soil absorb some nitrogen, as well as much oxygen, and so act to make a part of the nitrogen of the air available for feeding plants.

In other experiments, made at the ordinary temperature of the air, he found that the presence of oxygen seemed to hinder the fixation of nitrogen, and he argued that this would naturally be the case, since, when oxygen is present in abundance, it would combine continually with the nascent hydrogen and allow very little chance for nitrogen to do so. But on exposing wet sawdust, with or without lime, humus from old trees, or, best of all, mixtures of glucose and soda, to nitrogen gas, instead of ordinary air, it usually happened that some of the nitrogen was absorbed and fixed. There were formed nitrogenized compounds that were capable of yielding ammonia on being ignited with soda lime. It appeared in these trials that the fixation of nitrogen by carbonaceous matters can occur even at the ordinary temperature of the air, though more readily at higher temperatures. According to Avery, mixtures of glucose and dilute solution of soda ferment readily when seeded with the lactic ferment and heated. They yield hydrogen freely, as well as lactic acid.

Still later, Dehérain tried experiments with sawdust, humus from old trees, decomposed wood, and glucose mixed with lime, potash, soda, or ammonia, and often found that appreciable quantities of nitrogen were fixed from the air, notably in cases where the old wood and the humus were employed. He found, as before, that the presence of oxygen was detrimental, and agreed with Mulder, that nitrogen from the air can perhaps be more readily fixed in the lower layers of the soil than near the surface, where oxygen is abundant. He urged anew that fermenting or decaying organic matters, such as occur naturally in the soil, evolve hydrogen, which, when nascent, unites with free nitrogen from the air to form ammonia, which enters into combination with carbonaceous matters to form substances analogous to those naturally produced in the soil by the decomposition of vegetable matter.

With the advance of knowledge, the results of all these experiments have become much more intelligible, since it is now evident that they must have been brought about by the action of microscopic organisms. That is to say, the reactions described depended on biological, rather than upon chemical conditions. The very fact that Dehérain in his experiments, met with frequent failures shows the real merit of his work. It can now be seen plainly enough that no nitrogen could be fixed in his experiments unless some germs of the necessary micro-organisms happened to become mixed with the contents of the flasks.

Avery's Observations.

Several years ago, my friend, Mr. C. E. Avery, while working out his patented process for making lactic acid in the large way, was impressed with the idea that nitrogen compounds are continually formed by the union of free nitrogen from the air with the nascent hydrogen which is known to be developed during many kinds of fermentations. Under date of February 20, 1885, he wrote to me the following statement: "In my fermentation studies, it seems to me that the source of the nitrogen supplied to plants is plain; all the steps are now proved, we only want the experimental link. The nitric ferment, when air and calcic carbonate are present, oxidizes ammonia to nitrates, the direct food of plants. The ammonia is known to form whenever nascent hydrogen is released in the presence of free nitrogen, that is to say, of air. Now, when glucose or lactic acid, or many other vegetable bodies ferment, nascent hydrogen is released as in the butyric fermentation,

$$C_6H_{12}O_6 = C_4H_8O_2 + 2\ CO_2 + H_4.$$

But, as appears from pages 583 and 584 of Vol. III, Part II, of Roscoe and Schorlemmer, pine wood, poplar wood, and lignin yield glucose in fact in presence of water, albuminoids, and nutritive salts. Wood is well known to ferment rapidly, to its destruction, — the starch, inulin, sugar, etc., in it adding to the amount of hydrogen which is set free. Have we not here a complete cha of known facts, and a theory of the old barnyard plan of manuring? Many other ferments beside the butyric release hydrogen. See Schützenberger, for example, in his book 'On Ferments.'" In a subsequent letter, dated March 22, 1885, Mr. Avery insisted that experiments tried by himself upon loam clearly indicated the occurrence there of fermentations, such as occasion the evolution of hydrogen. His words were as follows: "I have run two fermentations of garden soil, from flower-pots, in contact with calcium carbonate, with supernatant water at 110° F., and find that carbonic acid comes off lively. Hence lactic and butyric ferments are almost certainly present; also glucose yielders." And, alluding to the observation of Zabelin ("How Crops Feed," p. 80), that ammonia is formed upon bits of paper or linen (i. e. cellulose) wet with water and heated in the air to from 120° to 160° F., he added, "I have myself found that in faintly alkaline solutions these fermentations run well at what are usually thought to be killing temperatures."

Finally Winogradski has isolated from the soil and has "cultivated" micro-organisms which when fed with glucose and ash-ingredients rapidly absorb and fix the nitrogen of the air. Meanwhile the sugar is decomposed with evolution of carbonic, butyric and acetic acids and large quantities of hydrogen.

Fixation of Nitrogen by Symbiosis more important than its Fixation by "Ferments."

In the light of existing knowledge, it may be regarded as proved that some nitrogen from the air is really fixed as an incident to certain fermentations which occur in the soil. The fact is one of the utmost importance when geologically considered, and enough has been learned already to show that it has great agricultural significance, even in the immediate economic sense. But it needs to be said that, practically speaking, the fixation of nitrogen by micro-organisms living in the soil appears to be of far less agricultural importance than the fixation of nitrogen by the bacteria which live upon the roots of leguminous plants. As Hellriegel has urged, it is a fair presumption that the nitrogen fixed directly by micro-organisms living in the soil, as observed by Berthelot, should be put to profit as readily by oats, barley, buckwheat, etc., as by leguminous plants; yet, in point of fact, the cereal grains are not seen to get any immediate good from the free nitrogen of the air, while luxuriant crops of leguminous plants may be grown by means of it, thanks to the bacteria upon their roots.

Increase of Fertility on Uncropped Land.

The fixing of free nitrogen from the air by fungi, of whatever name, evidently throws much light on the familiar fact that land left to itself in a state of nature, often increases in fertility with the course of years, and is found to be the more fertile — as in the forests and prairies of our own country — the longer it has remained uncultivated. Excepting arid and frozen regions, there may be seen all over the world mountains of mere rock, whose sides are luxuriantly clothed with vegetation, barring only those spots where flowing water has opportunity to sweep the ledges bare, and where, from the nature of the slope, not enough moisture for the support of large plants can be retained in the soil. It is easy enough to account for the presence of the non-nitrogenous constituents of the mountain soils by considering how the rocks have gradually disintegrated at the surface, and how plants have continually grown and decayed upon these soils of disintegration, but it was not easy to account for the accumulation of nitrogen in soils in such situations until evidence had been adduced that something in or upon the soil has power to fix nitrogen from the air.

CHAPTER XVI.

CARBONIC ACID AS A MANURE.

THE importance of carbonic acid for the plant has been stated in some part in an earlier chapter. It will be well, however, to consider this substance further as if it were a manure, and to inquire more particularly as to the modes of its action, and as to the possibility or advisability of increasing or controlling the natural supplies of it.

As has been shown already, there is a never-failing supply of carbonic acid in the atmosphere, into which the gas is constantly thrown by processes of combustion, decay, and fermentation, by the respiration of animals, and, in many localities, from mineral springs, volcanoes, and fissures in the earth. The gas is found in abundance in the pores of the soil, also, and dissolved in the waters of the rivers and ponds of those regions where the soils are calcareous.

Atmospheric Supply of Carbonic Acid.

As is now well known, it is from the air that green plants get the chief part of the carbon which is contained in them; hence it is of interest to reflect, that, although the proportion of carbonic acid in the air is only about 1 part by weight in 2,000 parts of air, — or, in terms of volumes, 1 part in 3,300 parts of air, — there is still enough of the gas to amount to three or four trillions of tons in the whole, or to some 28 tons of carbonic acid for every acre of the earth's surface. In spite of the enormous quantities which must be incessantly consumed by vegetation, as is indicated by the merest glance at such free-growing plants as tobacco, fodder-corn, sunflowers, or the eucalyptus tree, for example, there is really no difficulty in conceiving that crops are abundantly supplied with this form of food.

According to Boussingault, who carefully examined a whole course of field crops, consisting of potatoes, clover, wheat (and turnips), and oats, some 1,500 lb. of carbon were produced on the average, in one year, by the crops taken from an acre of well-dunged land. Lawes and Gilbert found that the mixed herbage of an old mowing field, which yielded, without manure, 2,700 lb. hay to the acre, or one long ton of dry substance, must have assimilated from the air as much as 900 lb. of carbon to the acre. On applying to this land a mixture of ammonium salts and ash-ingredients, but no carbon, the crop was increased to 7,000 lb. of hay, or 5,700 lb. of dry substance, so that as much as 2,280 lb. of carbon had been assimilated from the air in this case.

In like manner Chevandier has calculated that an acre of thrifty beech-trees may assimilate in a year some 1,500 or 1,600 lb. of carbon, or say 3 tons of carbonic acid. Yet so large is the amount of carbonic acid in the air, that if the whole earth were covered with a forest of the kind specified, it would take nine years for this forest to consume an amount of carbonic acid equal to that now actually contained in the air. This computation, it should be said, is based on the analyses of De Saussure, which indicated that the air contains 6 ten-thousandths parts, by weight, of carbonic acid, whereas more recent investigations point to the conclusion that the number 6 twelve-thousandths is nearer the truth.

Stirring Action of Winds.

It has been shown, by numerous analyses made in different places, and at different times in one and the same place, that the proportion of carbonic acid in the air is remarkably constant. That is to say, the variations to which the amount of the gas is subject are commonly small. Of course the amount of carbonic acid may sometimes be increased unduly in comparatively small volumes of air, as when a forest burns, or a volcano is in action, or a lime-kiln, or where a crowd of men or animals are congregated; but, thanks to the stirring action of the winds, these local variations are quickly lost in the great ocean of air.

The ventilating power of the wind is something enormous. Air moving no faster than two miles an hour, which is almost imperceptible, if allowed to pass freely through an open shed, will change the air of the place 528 times in an hour.[1] Hence, having regard to their respective requirements, carbonic acid is, to all intents and purposes, supplied as freely to plants by the air as oxygen is supplied to animals. It is well that this is the case, for, practically speaking, it would not be an easy matter to control the proportion of carbonic acid in the air. In the culture of field crops, at least, we could hardly hope to be able to alter the relative proportions of the ingredients of the air, as we can and do alter those of the soil.

Enough Carbonic Acid in the Air.

It does not appear, for that matter, that there would be much use in increasing the supply of carbonic acid in the air under the conditions of temperature and sunlight which now prevail. The experiments of Hellriegel have shown that an artificial supply of carbonic acid, added either as gas in the air or as a solution in the soil, had no effect to increase the yield of a crop of barley, or other grain, that was amply supplied with all other kinds of food. Hellriegel urges that the atmospheric supply of carbonic acid is probably sufficient for the production of a maximum crop under all circumstances.

This conclusion, it should be observed, does not conflict with the results of experiments in which carbonic acid water has been found to be advantageous for plants growing in poor soils, since in this case the useful effect is to be attributed to the solvent action of carbonic acid on the constituents of the soil. Hellriegel's conclusion has been arrived at by Knop also, and other experimenters operating by the method of water-culture and upon other kinds of plants. It had been argued, formerly, of woodland, that the increased growth obtained by thinning out some trees from dense groves might be due to a larger supply of carbonic acid brought to the trees by the freer circulation of the air; but it is to be presumed that the observed benefits should really be attributed to the facts, that, after the thinning, the trees have more room to grow in, and that more light now falls upon their leaves.

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[1] For a detailed statement of the amounts of carbonic acid which may be brought to an acre of land by winds of varying degrees of force, see "How Crops Feed," page 220.

In corroboration of Hellriegel's observation, it is to be noted that in the experiments of Lawes and Gilbert, where field crops of wheat were grown continually during more than 40 years, no beneficial effect resulted from the use, as manure, of organic matter yielding by its decomposition carbonic acid (or other compound of carbon) within the soil; whence the conclusion again, that the wheat-plant, when properly supplied with other forms of food, is practically independent of any supply of carbon added in the manure. It is able to obtain and assimilate from the atmosphere all the carbon it needs, if only the necessary amounts of nitrogen and of mineral ingredients be present in the soil in available form. Some of the plots devoted to wheat-growing had not received an ounce of carbon in the fertilizers during the whole course of the experiment; yet it appeared that in the course of 37 years the crop dressed with purely mineral fertilizers has assimilated about 1,000 lb. of carbon per year and per acre, and that in those instances where nitrogenous fertilizers were used in conjunction with the minerals an average of 3,500 lb. of carbon were harvested annually from each acre of land, although no carbonaceous manure had been applied.

It appeared furthermore, that barley and grasses were equally independent, with wheat, of any need that carbon should be supplied by means of decomposing manure, and although they reported at one time that graminaceous plants "as compared with other crops, appear to be most strikingly independent of any artificial carbonaceous supply," and were led to infer that some of their root-crops seemed to be greatly improved by a supply of carbon from organic matter decomposing in the soil, they finally reported that "with sugar-beets, larger amounts of carbon have been annually accumulated without the supply of any to the soil, but under the influence of a liberal provision of both nitrogenous and mineral manures, than by either wheat or barley."

It should be said, however, that it has long been a matter of belief among practical men that turnips, and especially rape, do actually feed upon organic matters in the soil; and an experiment of Corenwinder seemed at one time to support this idea, for he found that sugar-beets grew much larger, during the later period of their growth, in rich mould from rotted horse-dung, than in sand free from organic matter that was fertilized with solutions of chemicals.

Do Root-crops need Carbon?

As regards this supposed advantage, to root-crops, of organic manures, it needs to be considered that while some kinds of plants assuredly have no need whatever of taking any organic food from the soil, there are other plants (fungi) which cannot live without such food; and that, as Sachs has suggested, there may well be intermediate kinds of plants which can put to profit at one and the same time both carbonic acid and the carbonaceous constituents of organic matters. It is well enough known that chlorophyl grains are not wholly absent from some kinds of parasitic plants and of some plants which feed chiefly upon humus, and it is to be presumed that such plants may decompose carbonic acid by means of their chlorophyl at the same time they are feeding on the sap of the plant to which they are attached, or upon the humus of the soil.

On the other hand it is manifest that all plants which spring from seeds must in the beginning feed upon the carbonaceous matters of the seed, until such time as chlorophyl has formed in their leaves, and there is no improbability that certain kinds of agricultural plants may continue to feed in some part on the organic matters in manure or in vegetable mould. Gasparin often dwelt upon the sentiment of practical men that carbonaceous manures are specially helpful for certain kinds of plants such as beets and potatoes and grape-vines, and Dehérain has put upon record his own belief in the truth of this idea. He argues that a part of the organic matter in soils which have been repeatedly dunged probably serves as direct nutriment for the sugar-beet and for some other kinds of plants, notably for hemp, maize and clover; though it may well be asked in all these instances whether the benefit should not be attributed directly to the nitrogen contained in the manure, since there are several reasons for believing that root-crops do habitually get nitrogen from other compounds of this element beside nitrates.

As was just now intimated, it is by no means impossible that root-crops may put to profit other compounds of carbon than carbonic acid, obtainable from organic matters; and it may perhaps be discovered one day that some microscopic organism growing upon the roots of beets or turnips may have been the cause of the improved growth, but for the present it remains to be shown whether the advantages which have occasionally been derived from applications of sawdust, straw, farmyard-manure and other carbonaceous matters may not really have depended on the fact that these materials acted as a mulch to increase the supply of water for the root-crop, or, upon their having favored the growth of useful micro-organisms and so increased the fertility of the land. In a word, while it is not impossible that the root-crops may profit from some other compound of carbon than carbonic acid, obtained from organic matters; it would seem to be more probable that the carbonaceous manure in these cases may have acted either as a mulch to increase the supply of water for the root-crops, or have favored the growth of useful microdemes, and so increased the fertility of the land.

Carbonic Acid given off from the Roots of Plants.

Corenwinder and Knop have observed that plants upon which they experimented by way of water-culture gave off very considerable quantities of carbonic acid from their roots; and similar observations were made many years earlier by De Saussure, by Wiegmann and Polstorff, and by Boussingault. This evolution of carbonic acid by roots is manifestly a simple consequence of the natural "respiration" of the plant. Cauvet has noticed that bean-plants evolve much more carbonic acid from their roots by day, and especially before noon, when the plant is most active, than during the night, when the plant is at rest, comparatively speaking. In Corenwinder's experiments where the water in which the plants were standing was kept in contact with air to which a known volume of carbonic acid gas had been added, it appeared that, far from any reduction of the amount of carbonic acid in the air and in the water having occurred, the quantity of it was distinctly increased by the addition of that thrown off by the roots.

Plants can decompose more Carbonic Acid than the Air supplies.

Although it has been satisfactorily proved that well-fed grain crops derive no benefit when supplied throughout their entire term of growth with more carbonic acid than they would naturally find in the air, it is still true that plants can decompose a considerably larger proportion of carbonic acid than is usually contained in the atmosphere.

Godlewski has shown that, when the amount of carbonic acid in air is somewhat increased, plants decompose it readily up to a certain point of best action. But when a still larger proportion of carbonic acid is presented to them, it is hurtful, and their power of decomposing the gas is diminished. In the case of the grass Glyceria spectabilis, he found the best action on clear days, when the proportion of carbonic acid in the air was between 8 and 10 %; while for Typha latifolia the best action occurred when the proportion of carbonic acid was between 5 and 7 %, and for an oleander the best proportion seemed to be still lower. He found in general that starch formed in the chlorophyl grains four times more rapidly in air that contained 6 or 8 % of carbonic acid, than in air which had only the normal amount of this gas. But when more than 8 % of carbonic acid was present, the formation of starch was slower. The advantage derived from an increase in the proportion of carbonic acid was the more marked in proportion as the light was stronger to which the plant was exposed.

So, too, Schützenberger, by experimenting with the water-pest, Elodea canadensis, in ordinary water and in water that had been mixed with carbonic-acid water, so that from 2[1] to 40% of carbonic acid should be present, found that up to a certain point the plant developed oxygen more freely according as more carbonic acid was present, but that too large a proportion of the carbonic acid was injurious.

Godlewski found that the decomposition of the carbonic acid was favored much more by an increase in the proportion of it below the point of best action, than it was hindered by a similar increase above this point. So, too, in proportion as the light was more intense, the decomposition of carbonic acid was the more favored by an increase of the carbonic acid up to the point of maximum action, and less hindered by such increase beyond this point. The more carbonic acid the air contained, so much the more was the decomposition of it promoted by an increase in the intensity of the light.

Above the point of best action, the decomposition of carbonic acid by leaves diminishes more and more as the proportion of it in the air is increased, until in pure carbonic acid the decomposition becomes so feeble that it might almost be said to cease entirely. Some slight action does go on, however, and it tends to increase when the experiment is persisted in for some little time; for the oxygen which results from the slight action that does occur is of course thrown into the atmosphere of carbonic acid which surrounds the leaves, and so gradually weakens it.

The hindrance to the action of the chlorophyl grains thus caused by pure carbonic acid, or by any undue amount of it in the air, is thought to depend upon the presence of too dense a coating of it, caused by the excessive pressure which it exerts upon the leaves; for it is found, when this pressure is removed from the leaves, that they can decompose carbonic acid readily enough, even when it is pure and not admixed with any other gas. Decomposition sets in at once when the atmosphere of pure carbonic acid is somewhat rarefied by means of an air-pump. So, too, when pure carbonic acid is diluted by being mixed with an inert gas, such as hydrogen, oxygen, nitrogen, carbonic oxide, or marsh-gas, the decomposition of it by leaves will go forward. Conversely, if carbonic acid is mixed with an inert gas, and the mixture is subjected to pressure, the power of leaves to decompose it will be diminished. Boehm found that, while carbonic acid was freely decomposed by leaves in a mixture of equal volumes of carbonic acid, and hydrogen kept at the ordinary pressure of the air, the decomposition was reduced to a minimum when the mixture of gases was subjected to a pressure of rather more than 1¼ atmospheres.

Plants suffer from an Excess of Carbonic Acid.

Practically, most plants cannot long support large quantities of carbonic acid. Boussingault found that leaves were asphyxiated when confined for some time in the dark, in an atmosphere either of carbonic acid, nitrogen, hydrogen or marsh gas. After this treatment, they had no power to decompose carbonic acid in sunlight. By the long-continued deprivation of oxygen, the leaves had lost their power of respiring. The cells within them had, in fact, been killed. Boehm concluded, from his experiments, that more than 2 % of carbonic acid is hurtful to plants, and that 20 % of it kills them. Davy, in his day, taught that, while many plants will continue to grow for some time in air that contains from one-half to one-third its bulk of carbonic acid, they are not so healthy as when supplied with smaller quantities of the gas. He found that some few plants withstood fairly well the action of air that was highly charged with carbonic acid, and that one, Arenaria tenuifolia, was capable of producing oxygen in carbonic acid that was almost pure.

Daubeny, who experimented in 1848, both on flowering plants and ferns, found that the plants remained to all appearance unaffected for a fortnight when exposed to air that contained from 5 to 10 % of carbonic acid. A few of the ferns began to suffer somewhat at the end of a month, but a Pelargonium bore perfectly well during 27 days an atmosphere that contained 10 % of carbonic acid. When exposed at once to air that contained 20 % of carbonic acid, many plants were evidently injured even in 2 or 3 days, or certainly in 8 or 10 days. Even when added gradually, 20 % of carbonic acid was decidedly injurious. Thus, on keeping ferns in air to which 1 % of carbonic acid was added daily until the proportion of it had reached 20 %, and maintaining the air in this state for another term of 20 days, it appeared that most of the plants suffered severely, and that so large a proportion of carbonic acid must finally have proved fatal to them.

Twenty per cent of hydrogen, on the contrary, appeared not to exert any sensible influence upon the health of the plants, in the course of ten days. Daubeny found in these experiments that the evolution of oxygen from the plants did not keep pace with the increased supply of carbonic acid, and he inferred that, when the carbonic acid in the air exceeds a certain amount, the power of leaves to decompose it is in a great degree suspended.

Several species of ferns kept by Daubeny in air charged with 5 % of carbonic acid were no more vigorous after 11 weeks' time than similar ferns kept in ordinary air. But on watering ferns with water that was moderately charged with carbonic acid, their growth was perceptibly improved.

An Excess of Carbonic Acid may do Good.

De Saussure long ago found that young pea-plants could support at intervals for some days an atmosphere of one-half carbonic acid; but when the proportion of the latter was increased to two-thirds or more, the plants soon withered. In air that contained 8 % of carbonic acid the young pea-plants seemed to thrive better than in ordinary air, so long as they were exposed to sunlight; but in the shade this amount of carbonic acid was hurtful to the plants. De Saussure's method of operating in these experiments, where carbonic acid seemed to favor growth, was to expose the plants during five or six hours daily, or as long as sunlight was to be had, to the air charged with carbonic acid, and to supply the plant with ordinary air during the remainder of the day. These results manifestly consist with those of Godlewski, above cited, both as regards the influence of strong light and the increased decomposition when more carbonic acid than usual is present in the air. De Saussure's trials lasted during ten days or so, and he operated upon young plants. It seems not at all improbable that, if it were economically possible to provide an extra supply of carbonic acid during the hours of sunlight to plants at a certain stage of development, it might be advantageous to do so as a means of securing to the crop a good start in life, or perhaps even a more rapid development of the crop during the earlier stages of its growth, although, as Hellriegel has shown, there may not be the least use in keeping up the excess of carbonic acid after the plants have once been well grown in youth.

Pfeffer has urged as a general proposition, that leaves which are well lighted and exposed to ordinary air must evidently decompose less carbonic acid than they are capable of decomposing, because, as things are now, this gas cannot be brought to them rapidly enough by diffusion; whereas, if the proportion of carbonic acid were to be increased within favorable limits, as in the experiments of De Saussure and Godlewski, the leaves might be made to work to the utmost limit of their capacity.

The question as to the significance of a larger proportion of carbonic acid than now exists in the air, is one of great general interest. It was believed at one time that the presence of an excess of carbonic acid in the atmosphere of early geologic periods must have had an important influence on the growth of vegetation. The argument was that if the earth did once cool down from the molten condition, it is a not unreasonable supposition that there may have been much more carbonic acid in its atmosphere at the time when plants began to grow upon the cooled crust, or in the waters upon it, than there is in the air now; for there is at the present time a vast amount of carbon stored up as coal, peat, and humus, and in limestones and other rocks, which in all human probability originally existed in the form of carbonic acid gas. It was supposed that the plants of those days were adapted to the circumstances which surrounded them, that they did actually decompose carbonic acid more rapidly than most of their successors, and that they were able to dispose of and stow away, as it were, the carbonaceous compounds which resulted from such decomposition.

An objection to the foregoing view is found in the fact that ferns and other plants allied to those of the coal-measures cannot, as we know them to-day, support an excess of carbonic acid; and that abundant fossil remains of air-breathing animals are found lying in contact with the coal. It has been suggested indeed by Hunt, that carbonic acid is continually passing into the earth's atmosphere, by way of diffusion, from external space, to make good whatever quantities are abstracted from the air by plants or by disintegrating minerals. In this view, the stores of carbon now upon the earth's surface have accumulated slowly, and at all times, rather than at any one geological epoch, through the decomposition of highly diluted carbonic acid, as at the present day.

Carbonic-acid Water a Carrier of Plant-food.

Though the furnishing of carbonic acid to the soil may be of no direct use as a source of carbon to the crop, it is to be presumed that when held in combination with carbonate of lime (or with carbonate of magnesia), as it is in many soils, it may act to dissolve various kinds of plant-food and to make them available for plants. The experiments of Beyer have shown that water which contains bicarbonate of lime in solution is a more powerful solvent for feldspar than mere water is, and it is to be inferred that in those cases where the presence of calcareous matter in the soil permits of the retention of the carbonic acid — which has been formed there either through chemical decomposition of organic matters, or by the action of micro-organisms or of living plants — it may often be useful as a means of supplying ash-ingredients to crops.

Pavesi has examined pebbles of a granitic rock taken at a depth of 26 feet from a moraine near Como which had long been exposed to the action of soil-water that was more or less charged with carbonic acid. He found: —

	In the corroded Rind of the Pebbles.	In the Natural Stone at the Centre of the Pebbles.
Matters soluble in hydrochloric acid	96.54	25.60
Carbonic acid	. . .	2.43
Oxide of iron	3.45	1.99
Alumina	. . .	66.91
Lime	. . .	3.21
	99.79	100.14

It would appear that in this case silicates of alumina and lime had been gradually changed from the insoluble condition to a state of comparatively easy solubility.

R. Müller digested the fine powder of many different minerals — feldspar of different kinds, hornblende, magnetic iron, apatite of several varieties, olivine, and serpentine — for two months at a time in carbonic-acid water, with the result that all of the minerals were more or less decomposed. The quantities of matter dissolved by the carbonic acid ranged from 0.307 % (magnetic iron) to 2.111 % (olivine and apatite), and consisted, in one case or another, of lime, phosphoric acid, oxide of iron, potash, silica, magnesia, and even alumina.

Similar results were obtained by Beyer (Hoffmann's Jahresbericht, 1870–72, I, 24), who caused carbonic acid to act for long periods upon powdered feldspar admixed with water and with various saline solutions. The results of such action are conspicuous enough in many mineral springs the waters of which are highly charged with carbonates of the alkalies, and alkaline earths, thanks to the action of carbonic-acid water upon silicated rocks and minerals in the bowels of the earth.

Action of Bicarbonate of Lime.

Actually, in regions where limestone prevails, and where the soils are calcareous, the ground-water usually contains very considerable quantities of carbonic acid loosely combined with carbonate of lime to form a soluble sesqui- or bicarbonate of that base. A. Mayer has observed that deep-lying ground-water from the neighborhood of Mannheim in Germany, contains on the average twice as much carbonic acid as of lime. That is to say, while bicarbonate of lime should contain 1.57 CO_2 to 1 CaO (88 : 56), the waters examined by Mayer contained from 1.57 to 2.45 CO_2 to 1 of CaO, or on the average, 2 parts by weight of carbonic acid to 1 part of lime, as was just now said.

The fact of the presence of the supercarbonate of lime is familiarly illustrated by the formation of stalactites in caves and cellars into which such waters drip. The water on coming into contact with the air gives up a part of the carbonic acid, and the carbonate of lime which the acid had held in solution is deposited. The waters of springs, wells, rivers, and ponds in such regions are, like the ground-water, more or less highly charged with the supercarbonate of lime, and highly favorable influences are exerted by this substance both for the formation of soils and of mellow, fertile humus, and for the nitrification of manures and other organic matters.

Little Carbonic Acid in Pure Water.

But, on the other hand, it has been observed that the water in some kinds of soils contains next to no carbonic acid, and it is to be inferred from what is now known as to this matter that the waters of non-calcareous soils in humid regions will usually contain very little or even none of it. As to rain-water, Schloesing has shown that only some traces of carbonic acid can be brought down by it out of the air, for many experiments have proved that the solubility of carbonic acid in water is such that any given volume of water saturated with the gas in presence of the atmosphere and under the normal pressure thereof can hold in solution no more of the acid than is contained in an equal volume of atmospheric air. But any given volume of air contains normally about three ten-thousandths of one part of carbonic acid, and a similar volume of rain-water could at the best contain no more than this quantity. Buchanan also has shown by direct experiment that pure distilled water artificially charged with carbonic acid and then exposed to the air gives off the whole of the gas in the course of a few minutes, and there is every reason to believe that the carbonic acid would be discharged from water still more quickly if the solution were to be brought into intimate contact with solid substances. In point of fact, the Dutch chemist Van den Broek observed long ago that wells sunk a few feet in the soil of gardens, near Utrecht, contain water so devoid of carbonic acid that they give no precipitate when tested with lime-water, though the deeper wells of the same region, which reach into the sandy subsoil, contain large quantities of carbonate of lime dissolved in carbonic acid.

On further examination, it was found that the garden soil contained an abundance of carbonic acid (in its interstices) which could be removed by a current of air. Yet a column of the earth 20 inches deep by 3 inches wide gave up no carbonic acid to pure distilled water which was made to percolate through it. More than this, a quantity of water that had been artificially charged with its own volume of carbonic acid gave up this carbonic acid when put in contact with the soil.

Decomposition of Carbonic-Acid Water by Solids.

The explanation of all this is doubtless to be sought for in a peculiar porosity of the garden soil, which permits air freely to enter it and pass through it. It is a well-known fact in natural philosophy, that when water charged with carbonic acid (or with any other gas, for that matter) comes into contact with solids which have been exposed to the air, the carbonic acid will escape from the water and assume the gaseous form. The appearance of air-bubbles on the sides of glasses in which drinking-water has been left standing is a familiar example of this phenomenon. And the same thing may be shown still better by putting a bit of bread or dry peat into stale beer or flat soda-water. In general, the rougher and more porous the solid is, so much the more rapid will be the evolution of the gas.

It appears that the carbonic acid originally held dissolved in the water, or the beer, diffuses out into the air or in upon the solid; and that it diffuses with extreme rapidity when brought into contact with a considerable quantity of air in a small bulk, like that entangled in the interstices of a porous solid, or that which clings to the surface of any rough body. It is much the same thing as when a current of air is made to bubble through a solution of carbonic acid, or of any other gas, whereby the carbonic acid, or what not, is rapidly carried away. Angus Smith found that "nitrogen and hydrogen, when absorbed by charcoal, diffuse into the atmosphere of another gas with such force as to depress a column of mercury three-quarters of an inch."

It is to be inferred that, in the absence of carbonate of lime, any porous soil will naturally act to set free carbonic acid which may be contained in the water which comes in contact with the soil; and it is probably true in general that soils as such tend to set free carbonic acid from the waters which moisten them. Moreover, when moving water strikes against, or falls upon, rocks or gravel, some carbonic acid will doubtless escape from it, in case any were contained in it. But, taking the world through, there are practically so many calcareous soils that the fact remains that, because of the presence in them of the calcareous matter, most ground-waters contain more or less carbonic acid, and that they act chemically in accordance with this composition.

Another point to be remembered is, that, even when the carbonic acid escapes from the ground-water, it does not necessarily escape out of the soil. Some of it will remain clinging to the particles of earth, and if there be anything in the earth for which carbonic acid has an affinity, it will be likely to unite therewith in spite of its adhesion to the soil. Indeed, it is not impossible that this very adhesion may increase the chemical action, and accelerate the union of carbonic acid with the inorganic ingredients of the soil.

Carbonic Acid in Ground-air.

It is a fact that the air in the interstices of most soils contains very much more carbonic acid than ordinary atmospheric air. Boussingault and Lewy, who studied this point long ago, found the soil-air to be from 10 to 400 times richer in carbonic acid than atmospheric air, as has been set forth in tabular statements on pages 139 and 219 of Johnson's "How Crops Feed."

In air from sandy soils that contained but little decomposing organic matter, the proportion of carbonic acid was found to be only about 10 times greater than that in an equal bulk of the atmosphere. The proportion of carbonic acid in the air from loamy and clayey soils was still comparatively small (some 30 or 40 times as much as in atmospheric air), while in the air from the soil of manured fields, and from compost-heaps, the quantity of carbonic acid was very large. It appears clearly from these researches, that very large quantities of carbonic acid are formed within the soil from the decomposition of manures, and of the roots and stubble of previous crops. By the application of peat also, or of composts in which peat is a principal ingredient, large quantities of carbonic acid are furnished to the soil.

Carbonic Acid may Improve Tilth.

As will be explained in the chapters on Lime and on Sodium Compounds, the solution of carbonic acid which is found in so many soils may exert no inconsiderable influence to improve the permeability and consequently the fertility of a soil by flocculating fine particles of clay which would clog the pores of the soil if once they were to be permitted to become puddled in it through the action of rain-water. In this point of view, it has been suggested that some part of the utility of humus in heavy soils may depend on flocculation brought about by the action of the carbonic acid which is formed continually in the soil through the decay of the humus.

Disintegration by Carbonic Acid.

It is obvious that the carbonic acid thus supplied to soils must play a very important part in disintegrating and dissolving the components of the soil. Some experiments of the German chemists Stoeckhardt and Peters bear upon this point. They filled several tall glass jars (2½ feet high by 5½ inches wide) with a rather poor loamy soil, containing considerable humus, and they planted in each jar an equal number of seeds of peas and oats. Jar No. 1 was left to itself; that is to say, it was merely watered. Through the earth of jar No. 2 about 3½ pints of air were blown daily through a tube that reached to the bottom of the jar.

Through the earth of a third jar the same bulk of a mixture of air and ¼ carbonic acid was forced, while through the earth of a fourth jar there was forced daily a mixture of ¼ carbonic acid, ¼ oxygen, and ½ air. After three months and a half the crops were harvested, dried thoroughly, and weighed. Their weights are given in grams in the following table:

	I.	II.	III.	IV.
Oats	3.90	7.65	8.49	5.11
Peas	1.72	2.46	3.26	3.49
Roots of both	0.27	0.38	0.60	0.37
Total dry matter	5.89	10.49	12.35	8.97
Ash-ingredients	0.52	0.95	1.12	1.01
If crop No. I equals 1, then	1.0	1.8	2.1	1.5

On examining the several soils after harvest, it was found that a considerably larger proportion of mineral and organic matters had become soluble in water in jars Nos. 2, 3, and 4 than in jar No. 1. From 6,000 grm. of soil, the amounts of matter dissolved by water were as follows: —

	I.	II.	III.	IV.
Mineral matters, grams	2.04	3.71	4.99	3.91
Organic " "	2.76	4.32	2.43	3.14

Carbonic Acid occluded by Soils.

Beside the carbonic acid in ground-air, properly so called, very considerable quantities of this substance are occluded in the actual earth; i. e. some carbonic acid and other gases are held so strongly in the soil that they cannot escape therefrom, either at the ordinary temperature of the air or even at the temperature of boiling water. By heating various soils to 284° F., Reichardt and his pupils have obtained results such as the following: —

From 100 Grams of	Gas given off, in c.c.	The Gas contained Per Cent of CO_2	N	O
A damp garden-loam	13.7	24.1	64.3	2.9
Air-dried garden-loam	38.3	33.3	64.7	2.0
Peat	162.6	51.0	44.4	4.6
Hydrated oxide of iron (air-dried)	586.7	68.2	26.1	5.7
Clay	32.9	14.5	64.7	20.8
Clay after long exposure to the air	25.6	25.1	70.2	4.7
Powdered gypsum	17.3	0.0	81.0	19.0
Pine charcoal	164.2	...	100.0	...
Poplar "	467.0	16.5	83.6	0.0
Bone "	84.4	45.8	54.2	0.0

This power of the soil to occlude carbonic acid and other gases is merely a particular instance of a general law which has long been recognized as regards charcoal and has latterly been found to be true of all solid substances.[1] The power of iron oxide to occlude carbonic acid is so well marked that it has been said that the amount of this gas occluded by a soil is proportional to the amount of iron contained in it.

Modes of Action of Carbonic Acid in the Soil.

As for the mode of action of carbonic-acid water in the soil, it dissolves some carbonates directly, such as carbonate of lime and carbonate of magnesia. From silicates, it dissolves out potash, soda, lime, and magnesia, since it is a more powerful acid than silica is at the ordinary temperature of the soil. As was stated before, it is easy to test this action by passing carbonic-acid gas through water that is made to hold in suspension almost any finely powdered mineral. Considerable quantities of potash, soda, lime, and magnesia may soon be found dissolved in the liquid. When made to act upon phosphate of lime, carbonic acid gradually removes lime, so that finally some soluble acid phosphate of lime is formed.

Little is known, as yet, as to the precise significance of the carbonic acid which is given off from the roots of growing plants, though there can be no question that the fact is one of much importance. Inasmuch as this carbonic acid can hardly fail to act upon matters in the soil to dissolve them, it would seem to follow that, in humid climates, there may often be as much, or perhaps more, disintegrating of rocky materials in a field kept covered with vegetation than if the field were left to lie naked and fallow;

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[1] Compare How Crops Feed, p. 165.

not to speak, for the moment, of the action of acids other than carbonic which are exuded or excluded by the roots of plants.

Carbonic Acid a Result of Ferment Action.

But, on the other hand, there are cases where the formation of carbonic acid in the soil probably depends more intimately upon fermentations due to the presence of micro-organisms than on the action of the roots of plants. I have myself found that very considerable quantities of bi-carbonate of lime are formed in air-dried soils,[1] probably by the action of micro-organisms acting at once on organic matters and on insoluble lime-compounds in the soil, such as silicates, humates, phosphates, etc.; and there are good reasons for believing that long-continued droughts may be useful in some cases by promoting peculiar kinds of fermentations in the soil whereby disintegration may become more rapid than would otherwise be the case and large quantities of carbonic acid be produced incidentally.

In confirmation of this view, it may here be mentioned that Hilgard has insisted that, although — as a consequence of the leaching action of rains — it is true, as a general rule, that "each subsoil is a little richer in lime-carbonate than its surface soil," the latter may nevertheless — at the end of the dry season — be found to contain more actual carbonate of lime than the subsoil, though during the following winter or rainy season the carbonate will be washed down into the subsoil so completely that in humid climates it may in the spring be almost wholly absent from the surface soil. "It follows that in arid climates, in which the rainfall is insufficient to leach the soil even of its very easily soluble alkali salts, the lime carbonate must of necessity accumulate to even a greater extent than the alkali salts. We should therefore expect to find the soils of the region west of the 100th meridian in the United States, and generally those of arid regions everywhere, richer in lime than those of the humid regions." In point of fact, it appears on comparing many analyses of good non-calcareous soils, that while the soils of arid regions contain on the average something like 1.362 % of lime, those of humid regions contain no more than about 0.108 %.

Wollny, in experiments lasting from May to October, found in air taken from the soil at a depth of 10 inches beneath grass-sod, 4.4 % less carbonic acid on the average than was contained in air taken at the same depth from beneath bare land, and 3.4 less than was taken from land whose surface had been kept shaded by a covering of straw. In general he found less carbonic acid in the air of the soil in proportion as the surface of the soil was more thickly covered with vegetation. In some experiments, however, that were made in November, March, and April, i. e. at a colder time of year, more carbonic acid was found in the air of the soil that was covered with grass than in the air of the bare land.

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[1] See Bulletin of the Bussey Institution, 1878, II, 195.

CHAPTER XVII.

GREEN MANURING.

Many substances employed as fertilizers produce such large quantities of carbonic acid in the soil that it is but natural to ask whether some part of their utility may not be due to this peculiarity. Farmyard-manure, for example, as well as composts, leaves, straw, and seaweeds, are comprised in this category; and especially the method of fertilization known as green manuring.

For warm or temperate climates, it is a commonly accepted opinion, that, if time enough be allowed, almost any land not absolutely arid or poisonous can be made fertile by persistently sowing upon it lupines, vetches, cow-peas, or clover of one kind or another, and ploughing in the green crop before it has come to maturity.

This method of green manuring, as it is called, is a singularly philosophical method. As a mere matter of reasoning, or of reasonableness, it will well repay a careful examination. In the first place, the seeds of plants are sown, which, like peas or clover or lupines, have a peculiar faculty for profiting by food taken from the air; or plants are chosen which, like the lupine, or like buckwheat or rye, have the power of extracting nourishment from the earth even under very unfavorable conditions. These plants are allowed to grow until they have gathered from the soil almost the whole of the matters which they are capable of gathering; that is to say, the plants are left until they are in flower, and then they are ploughed under. By operating in this way, the land is manured with everything that the plants have accumulated, either from the air, or from the soil, or from the waters in the soil; and there is placed within the land a mass of soft, fresh, succulent organic matter, which speedily enters into fermentation, and causes the soil to ferment also, while enormous quantities of carbonic acid are given off to disintegrate and dissolve the components of the crude soil.

The process is manifestly akin to the method of concentration by which fertile loams have been accumulated naturally on the earth's surface, for the roots of plants work continually to bring up plant-food from the subsoil, while some of them take in food from the air, and this food is deposited, in easily assimilable forms, on the surface of the land by the leaves that fall and by the plants when they decay.

Humus itself is Important.

The organic matter thus incorporated with the soil will furnish an abundant supply of humus for absorbing and holding moisture, for supplying nitrogen, for encouraging useful fermentations, and for improving the texture of the land. Hence it happens that, by means of this system of green manuring, many a leachy, hungry soil may, with comparatively little trouble, be made capable of retaining water and manure, and so of supporting crops. By cultivating the white lupine to this end, it has been found possible in Saxony to cover mere drifting sands with useful vegetation.

Instances are not wanting in agricultural practice of fairly fertile soils which consist naturally of no more than a small proportion of humus admixed with mere sand. Boussingault noticed in South America a very fertile soil that was composed of 92 % of sand admixed with leaf-mould. It is said that in Belgium many instances occur where arid sands have been made fertile by continually applying to them street-sweepings and stable-manure. In such cases, the humus appears to act very much in the same way that clay would act to improve the physical texture of the soil, and so enable it to hold water and fertilizing matters.

Generally speaking, green manuring is practised on poor, thin soils, notably upon such as have become hard and out of condition, and it is perhaps the readiest means of bringing such land into a proper state of fermentation; but it is said that even heavy clays have often been benefited by green manuring, in that the introduction of organic matter has made the clay less adhesive and sticky than it was before, and better fitted to support the operations of tillage.

Plants used in Green Manuring.

Among the plants which have served for green manuring the lupine is perhaps the most conspicuous, though in modern times cow-peas, rye and buckwheat are often used. According to Pliny, the ancient Romans sowed lupines in September and ploughed under the green plants in the following May; or, sometimes, they mowed the crop and carried it to be buried at the foot of fruit-trees or of grape-vines. In Italy, and other southern countries, the horse-bean, like the lupine, has often been used as green manure. Other plants that are sometimes ploughed under are turnips, sown thick, white mustard, Indian corn, sown thick, and peas. In the words of an English farmer, "Mustard, or any plant of rapid growth which attains a smothering bulk, the seed of which costs but little per acre, is well fitted for being ploughed in as green manure, especially when it is an object to clean the land as well as to fertilize it." In some of our southern states, a kind of bean called the cow-pea is used largely, as vetches are in some parts of Europe.

In certain districts in Italy it has long been customary to fertilize the hemp-crop by means of a green manuring with horse-beans, which are forced with stable-manure and plowed under when they are in flower, at the moment when the land is made ready for the hemp. In this case, the bean-plants are reckoned as equal to half a manuring with farmyard-manure, and it is a traditional belief that particularly good hemp can be obtained in this way. The bean is chosen in this instance because it will grow on soils where lupines could not be grown with success.

As a forerunner of wheat, also, beans may be sown in that country, on moist land, either in August or October, according as they are to be ploughed under before sowing wheat upon them in the autumn or before sowing spring wheat. On dry land, the beans are usually sown in October and ploughed under as a preparation for spring crops, though one plan is to sow another crop of beans in the spring — between the rows of those sown in the autumn — at the time when the latter are hoed, and to harvest the seeds of the older crop and then to plough under the spring-sown plants.

It will be noticed in respect to beans and to other leguminous plants that much which has been said in the chapter on Symbiosis of the power of clover, lupines and the like to procure nitrogen from the air will apply very forcibly to the practice of green manuring, in so far as such plants are concerned in it. As Gasparin insisted half a century ago, the leguminous crops are intrinsically superior to all others for the purpose of green manuring, because they bring in much plant-food from the air and do not need to be heavily manured beforehand. The chief trouble is, as he says, the cost of their seeds. This view has been not a little strengthened, of course, by the discovery of the nitrogen-bringing power of the nodules on the roots of leguminous plants, but it still remains true that there may sometimes be good reasons for choosing plants such as rye, buckwheat, mustard, turnips or (especially) vetches, which vegetate rapidly and which can be grown late in the summer or early in the autumn, after the crop proper to the field and the year has been harvested. These plants occupy the land only a comparatively short time, when it would otherwise be left bare, and they take up from the soil very considerable quantities of nitrates which might have been leached out from the land by the autumnal rains.

In the mild climate of France, on soils that are not too stiff, vetches sown in August are sometimes left standing until the next spring, when they are ploughed under early enough not to interfere with the sowing of sugar-beets in April. If the weather continues to be open the vetches will not cease to grow during the winter. (Dehérain.)

In Central Europe, it is said to be well to sow these stolen crops immediately after the grain harvest, for, in spite of hot weather, the surface soil is then mellow and somewhat moist, and the conditions are not unfavorable for germination. Sometimes it may be better yet to sow the green-crop upon the grain in the spring, and so gain time for the better development of the plants. Experiments made in Germany by Strebel indicated that vetches sown on a loamy soil after grain as a stubble-crop produced a larger crop, i. e. more dry matter, than peas or lupines, or than clovers of various sorts. The yield of oats on the land where these crops had been ploughed under was increased in every instance, but to a profitable degree only after the vetches and the peas. But on the other hand — thanks to peculiarly good climatic conditions — decidedly better results were got from Swedish clover, hop-clover and serradella that had been sown upon wheat or rye. Here the yield of oats was largely increased. It was noticed that both the clovers, growing under the grain, produced roots, and nitrogen in the roots, more freely than they produced leaves and stalks, though the serradella yielded more leaves than roots.

Some writers on green manuring have urged that the plants suitable for this purpose may properly be divided into two classes, according as they are to be ploughed under in late summer or early autumn, as a manuring for winter grain, or to be turned under in the spring to serve for fertilizing a crop of Indian corn, or of potatoes or roots. In climates like that of New England rye will naturally fall into the second category, while old grass or clover sod may belong to either class. Buckwheat, mustard, etc., will belong to the first class.

In one sense, Green Manuring is a Common Practice.

It is evident that green manuring may sometimes be at its best when obtained incidentally by ploughing under the roots and stubble, or aftermath, of a useful crop, such as hay or clover or lupines, for in this event there will be no necessity to sacrifice a standing crop or to give up the use of the land during an entire season for the sake of charging the soil with vegetable matter. In this way, frequent use may be made of the process and all of its advantages be realized at comparatively small cost. It is noteworthy that this form of green manuring prevails generally upon the thin soils of New England where hay is the staple crop. For whenever the sod of old grass-land is ploughed under, the land gets the benefit of what is really a green manuring of considerable strength.

Throughout the Eastern States, and even in the immediate vicinity of Boston, the farmers generally keep most of their land in grass as long as the yield of hay continues to be fairly remunerative, and they count upon the old sod as a source of nutriment for subsequent crops.

One way of proceeding is to turn the sod under with the ploughshare, and to harrow in rye without adding any manure. Here the case is one of green manuring pure and simple. After the rye has been harvested its stubble is ploughed in, and the next year the land is planted with potatoes or corn or roots, — with addition of barnyard-manure, — as a preparation for laying the land down again to grass. The old sod is found to be thoroughly rotten and friable when the rye-stubble is turned in.

There are of course several other ways of dealing with the inverted sod. Some farmers plough it under in the spring, and plant potatoes upon it in the first year, or maize; others plough in August or September, and sow grass-seed at once, as soon as the old sod has been turned under. The rye method has been mentioned particularly, because it seems to be specially philosophical. Formerly, when it was customary in New England to grow late-ripening varieties of the potato, it was thought by some farmers to be good practice to allow the grass to get well started in the spring on sod-land, which was to be planted with potatoes so that the crop might be helped by the heat developed by the fermentation of the grass-sods.

Maize on Sod-land.

So, too, in respect to Indian corn, there is a reason why this crop is specially well fitted to be grown on sod-land. Since corn needs to be planted rather late here in New England, the sod-land can be left unploughed until the grass has sprung up and has covered the land with a green crop; and when the green sod is turned under, fermentation soon sets in; the sod decays rapidly, and nitrification succeeds the first fermentation in due course, so that whatever plant-food the young grass may have collected is probably fully utilized by the corn. Mere "spring ploughing" would not have given these results, i. e. not if the ploughing had been done before the grass-plants had had time to grow. It is not improbable that — in the days when Indian corn was their leading crop — the old habit of New England farmers of turning shallow furrows, such as merely buried the sod, may have been justified by the rapid nitrification of the vegetable matter; and a similar remark will apply to the popular prejudices which still prevail, viz., that shallow ploughing will usually serve very well for Indian corn, and that this crop can get more good than some others from manure which lies near the surface.

Some people have occasionally gone so far as to turn sods directly upon potatoes, as a means of planting. They plough three or four furrows in the sod, drop the "seed" in the fourth furrow, perhaps, and then turn the next furrow upon the sets as a covering. This plan is evidently a modification of a method employed in the damp climate of Ireland which consists in laying out the potato sets on the surface of unbroken grass-land and covering both the sets and the sod with a bed of earth.

It needs to be said that English writers have often made objection to the sowing of crops on newly broken sod-land, because of the risk of injury from the grubs and wire-worms which, as they say, are apt to be found in great abundance among crops planted on land where grass or thick weeds have been ploughed under. As Cobbett says, "When wheat is sowed in this country (England) upon a ley with once ploughing, the plant is very frequently much injured by these mischievous things. The wire-worm enters the spear just above the seed and eats out the heart. The brown grub keeps snugly just under the surface of the ground in the day time, comes out at night, bites off the plant nearly close to the ground, and re-enters its retreat." Hence the advantage of ploughing and fallowing sod-land until these pests are expelled.

Amount of Organic Matter in Sod.

An experiment made at the Storrs Agricultural School, at Mansfield, Conn., to determine how much vegetable matter is contained in an acre of grass-sod, gave the following results: The grass was timothy, with a slight admixture of red-top, growing in light loam, 7 inches deep, which rested on a yellow, compact subsoil; and about 2 tons of hay to the acre had been obtained when the field was mowed, on July 23. On Nov. 7, when the land was covered with a luxuriant second growth of grass about 3 inches high, the grass and roots were carefully collected from a measured fraction of the field, first to a depth of 6 inches and then to the depth of 3 feet, and they were dried (at 212° F.) and analyzed. There was found 8,223 lb. to the acre of dry grass and roots, taken to the depth of 3 feet; and analysis showed that these 4 tons and more of vegetable matter contained 90 lb. of nitrogen, 25 lb. of phosphoric acid, and 56 lb. of potash. It appeared, furthermore, that by far the larger part of the roots were near the surface of the land, for in the trial which reached only to a depth of 6 inches, there was obtained 7,606 lb. of dry grass and roots to the acre, and there was present in this matter 84 lb. of nitrogen, 24 lb. of phosphoric acid, and 54 lb. of potash. In a parallel experiment, the dry stubble and roots of cow-peas, taken to a depth of 3.5 feet, on Oct. 3, after the crop proper had been harvested, amounted to 1,095 lb. to the acre, and contained 15 lb. of nitrogen, 3 lb. of phosphoric acid, and 6 lb. of potash.

Gasparin, at the south of France, on the occasion of breaking up a lucern field, collected all the roots and stubble from a hectare of land (= 2.5 acres), and found that there were 16 tons to the acre; and as the proportion of nitrogen in this refuse amounted to 0.8 per cent, there must have been in the 16 tons 261 lb. of nitrogen. He remarks that practical men have found their advantage in feeding lucern roots to sheep. Boussingault, on the other hand, found less organic matter in clover-sod. A clover-sod from which a crop of 2,200 lb. of hay to the acre had been harvested, gave him 1,760 lb. of air-dried roots, etc., that contained 55 lb. of nitrogen.

Of course, when not only the roots and stubble of an old sod, but the green plants themselves, are turned under, very large quantities of organic matter and of nitrogen may be added to the land. Thus the Italian chemist, Sestini, on determining the weights of total crop and of nitrogen yielded by beans (Phaseolus) and by lupines, when grown to be ploughed under as green manure, near Rome, found 28 tons of the green bean-plants to an acre, and 19 tons of lupines. The bean-plants on an acre of land, taken when in blossom, contained 280 lb. of nitrogen, and the lupines 117 lb.

According to Gasparin, a fairly good crop of lupines should yield at least two tons to the acre of air-dried hay that contains 1.6 % of nitrogen, which would be equivalent to 64 lb. of nitrogen to the acre, without taking any account of the roots and stubble of the crop. An English crop, grown upon light land, which was examined by Voelcker, yielded (exclusive of roots) 21 long tons and 12 cwt. of green lupines to the acre. These green plants contained 0.38 % of nitrogen, or, all told, 184 lb. of nitrogen to the acre.

Green Manure in Vineyards.

Mack, in the Tyrol, has grown annual clover (T. incarnatum) between the rows of vines in a vineyard, and ploughed the plants under as green manure. The seed was sown at the rate of about 30 lb. to the acre, and some plots of the land were dressed with phosphatic slag, applied at the rate of 530 lb. to the acre, while other plots received no fertilizer. The clover grew to a height of 16 or 17 inches on the slag plots, and to a height of 12 inches on the others. On one of the slag plots, all the vegetable matter (including the roots, which were well developed and full of nodules) was collected and weighed. There were 21 tons of it to the acre. These fresh plants contained 0.25 % of nitrogen, which amounted to over 100 lb. of nitrogen to the acre. Mravlag also has tried similar experiments with vetches, and both these observers argue that, by forcing the green manure with phosphatic slag and with potash salts, vineyards may be manured in this way more cheaply than can be done by means of stable manure.

Dehlinger has calculated, from Wagner's data, that the amount of dry matter and of nitrogen yielded per acre by crops grown for green manure might be in the case of —

	Tons dry matter.	Lb. Nitrogen to the acre.
Mixed vetches and peas	3.33	220
Lucern	3.00	200
Red clover	2.00	111
Swedish clover	1.50	100

Vibrans, also, has collected data, as set forth below, for the sake of learning how late in the season leguminous plants may be sown in order to obtain a product large enough to serve as a useful green manuring.

VETCHES GROWN AS A STUBBLE CROP.

		Yielded German lb. per Morgen (= 0.631 acre) of Dry Matter.	of Nitrogen.
Sown on	Mown on		
19 July	26 October	1690	61.3
20 "	" "	1370	56.0
5 August	" "	933	40.0
20 "	" "	582	27.2
31 "	" "	332	16.0

When sown under grain on April 20 and mown on October 12,

Vetches yielded . . . 760 lb. of dry matter and 34.4 lb. of nitrogen
Swedish clover yielded . 1300 " " " 39.0 " "
Hop clover " . 910 " " " 30.0 " "

In other trials, hop clover grown on different fields, under grain, gave results as follows: —

Sown	Mown	Lb. Dry Matter.	Lb. Nitrogen.
27 May	31 October	758	28
1 June	31 "	853	26
10 April	12 "	910	30
31 May	26 "	863	31

It is said that, in our Southern States, the cow-pea, though a tender annual, will give, under favorable conditions — when sown broadcast at the rate of 2 bushels of seed to the acre — three cuttings during the season, and yield at each cutting from 2 to 4 tons of air-dried hay. (McCarthy.) It can support intense heat, and bear drought better than clover can. In experiments made at the N. C. Exp. Station, an increase of 10 bushels of wheat to the acre, over the yield on unmanured land, was obtained on land where cow-peas had been ploughed under as a preparation for wheat. Experiments at the Alabama Station showed that the weight of the vines was 6 times that of the roots, and that the yield of fresh vines varied from 1 ton to 6½ tons. The vines contained from 1.45 to 2.62 % of nitrogen. At the Louisiana Station, 1 acre of cow-peas yielded 3,970 lb. of organic matter, and there was returned to the soil 65 lb. of nitrogen, 20 lb. of phosphoric acid, and 111 lb. of potash. Of these matters, at least 8 lb. of nitrogen, 4.4 lb. of phosphoric acid, and 18 lb. of potash, were furnished by the roots. (Allen.)

Green Manure may act slowly.

A point to be noticed in respect to green manuring in Northern climates and dry seasons, is, that the inorganic matters and the nitrogen in the buried plants are only gradually given up, as a general rule, for the use of the next crop. Probably the living plant cannot consume many of the constituents of the dead plants until the latter have been completely disorganized. This point is one that needs to be borne in mind; it would be on the whole disadvantageous, though something might be gained by it occasionally. Macaire long ago grew wheat on a measured plot of land, and, after having harvested and weighed the crop, he heated the grain to destroy its germinative power, and chopped the straw fine, and spaded both straw and grain into the soil, so that everything which had grown upon the land was returned to it. He then grew wheat again on the plot, and noticed that there was an appreciable diminution of product; although, as he intimates, as good wheat grew on an adjacent (manured) field in the second year as in the first. In any event, it is hardly fair to compare green manuring too closely with the ordinary methods of applying fertilizers, for it is in some respects a law unto itself.

As will be shown in another chapter, there is no justification for the idea, on which Macaire's experiment was based, that the chemical substances which exist in plants are as good fertilizers as the compounds ordinarily used for manure. It should be remembered, meanwhile, that green manuring has always been more highly esteemed in southern countries, such as Italy, the south of France, and our own Southern States, than it has been in places where the climate is less warm. According to Gasparin, green manuring has long played an important part in southern Europe for fertilizing vineyards and olive trees. Not only are reeds and green twigs brought to the land to be ploughed under, but lupines and beans are grown upon the land for this purpose. It is recognized, moreover, that "these plants obtain nearly all their fertilizing elements from the air."

It is known that under favorable conditions green manure — especially that from leguminous plants — nitrifies readily, after it has been thoroughly rotted, and that it compares favorably, as a source of nitrates, with most of the other forms of organic nitrogen that are employed as manures. The results of some of Muntz's experiments relating to this point are given in the following tables. In three months' time there were formed from the given materials the stated numbers of milligrams of nitrate-nitrogen for each kilo of soil: —

From one grm. of	There was formed mgr. of nitrate-nitrogen.	
	In a light calcareous soil.	In a stiff clay soil not calcareous.
Sulphate of ammonia	268	5.1
Green lupines, buried	183	88.0
Dried blood	161	3.6

In this case the lupines lightened the heavy land, and allowed air to enter it for the support of the nitric ferments. In another experiment, an exhaustive crop — giant maize to be cut for ensilage — was grown on light land, that was well charged with ash-ingredients, to which the different kinds of fertilizers were applied at the rate of 100 kilos of nitrogen to the hectare. Eighteen days after applying the fertilizers there was found per kilo of soil the stated amounts of nitric acid: —

Plot dressed with	Nitric acid found, mgr.
Sulphate of ammonia	121.4
Green lucern, buried	86.0
Dried blood	72.2
No nitrogenous manure	14.5

Here again the green manure nitrified more rapidly than the dried blood. The yield of fodder-corn cut at the end of September is given in the following table: —

The hectare dressed with	Gave kilos of crop.
Sulphate of ammonia	66,000
Nitrate of soda	78,500
Green lucern	78,000
Dried blood	71,500
No nitrogenous manure	39,500

In winter (in France) buried green manure nitrifies but little, though the process of nitrification becomes active with the advent of the spring. The results given in the following table were obtained by Dehérain, on testing the amount of nitrates that passed off in the drain-water from fields that had been and had not been green-manured. During the times stated the given quantities (kilos) of nitrate-nitrogen passed off, per hectare, in the drain-water from land kept bare of vegetation, as follows: —

	26 Oct. to 24 Nov.	24 Nov. to 15 Dec.	15 Dec. to 4 Jan.	4 Jan. to 9 Feb.	9 Feb. to 22 Feb.	22 Feb. to 10 July.
Land not green-manured	1.49	4.38	2.47	1.92	3.06	18.50
Land where a crop of vetches had been ploughed under.	1.22	5.01	2.29	2.71	7.95	33.40

These experiments had to be given up in the spring, because a drought set in and the drains ceased to flow. It should here be said that Bréal maintains that nitrification is comparatively feeble in grass-land, and that grass-sod which has been ploughed under does not nitrify so readily as do the residues from leguminous crops.

Green Manuring rarely practised.

Excepting the turning-under of old grass-sod or clover-sod, or of grain-crops that have been partially winter-killed, green manuring is resorted to only in exceptional cases nowadays in northern countries, though it was once rather common in many localities in the days when commercial fertilizers were not to be had. In the Southern States of this country, however, it is said to be still a rather common practice to plough under the cow-pea. One good method proposed and practised by Ravenel, of Charleston, is to apply finely powdered phosphate rock ("floats") to the land on which the cow-peas are to be grown; so that, when the green plants come to be ploughed under, the refractory phosphate shall be subjected to the solvent action of a great mass of decaying vegetable matter, whereby some part of it may be made fit to be assimilated by subsequent crops.

In Japan, Kellner and his pupils have studied a local practice in which a leguminous plant, Astragalus lotoides, is used as a green manure for rice. After having applied to the land a phosphatic and a potassic fertilizer and lime in varying quantities, viz., 100, 200, and 400 kilos to the hectare, they grew a rice-crop upon the field and at the end of September they sowed seeds of the Astragalus between the rice-plants. After the rice had been harvested the young Astragalus plants were lightly covered, according to the custom of the country, with short straw, to avoid winter-killing, and on the 10th of May in the following year, when the crop was in full bloom, it was mown close to the earth, weighed and analyzed. Finally the green plants were dug into the soil to serve as manure for a new crop of rice.

There was found in the blooming Astragalus, 12.23 % of dry substance and 0.369 % of nitrogen, and the mean yield per hectare was 2540 kilos of dry matter and 76.8 kilos of nitrogen. It appeared that the plot which had received 100 kilos lime to the hectare gave a much better crop than the no-lime plot, and as good a crop as either of the plots which had received more lime. Beside the green manuring the land got a new dressing of phosphatic and potassic fertilizers, and lime as before. After time enough had been allowed for the fermentation of the green manure, rice was set out upon the land in June. The results of these experiments are given in the following table : —

Manuring.	Straw. grm.	Full Kernels. grm.	Tailings. grm.	Total crop. grm.
No green manure	536	412.7	3.2	952
Green manure, without lime	623	464.2	4.2	1091
Green manure with 100 k. lime to hec.	837	633.7	5.3	1474
Ditto 200 ditto	825	613.3	5.5	1447
Ditto 400 ditto	860	646.2	4.6	1511
A complete manuring (mixed fertilizers)	975	638.1	7.6	1621

Whence it appears that the green manure and lime were competent to produce a crop of grain equal to that got by a complete manuring, which contained an abundance of ammonia.

The following table gives the amounts of nitrogen taken off the land in the several crops, as determined by analysis : —

Manuring.	Nitrogen in the total crop. grm.	Nitrogen taken up from the manure. grm.
No green manure	7.43	. . .
Green manure, without lime	8.18	0.75
" with 100 k. lime to the hec.	11.84	4.41
" " 200 " " "	11.52	4.09
" " 400 " " "	12.18	4.75
Complete manuring (mixed fertilizers)	12.46	5.03

The average of nine plots fertilized with green manure and lime gave 53 kilos of nitrogen to the hectare as the amount taken up by the crop from the green manure; which, according to other experiments of Kellner, is equal to the amount taken up from a manuring of 85 kilos sulphate of ammonia to the hectare. Kellner heartily commends this method of manuring the rice-fields. When they are not thus treated, it is customary to leave them bare during the winter.

Clover as Green Manure.

In the same way that grass-sod is made to furnish green manure in New England, so is clover-sod in several European systems of rotation, as well as in the wheat-growing regions of New York and of several other American States. In these districts clover-seed is often spoken of as "a cheap manure."

Since clover forms a thick mat of roots, the turning-under of a mere dry stubble of it gives to the soil a considerable amount of nitrogenized organic matter in any event. But there is a system of culture occasionally practised in several European countries, in which care is taken to convert the stubble into greensward before ploughing it under. To this end, a portion of the fertilizing matters that would be allotted in any event to the next year's crop, is applied as a top-dressing to the field immediately after the clover has been mown. The abundant crop of aftermath thus obtained is then ploughed in at the farmer's convenience.

In view of the fact that a clover-crop treated in this way will bring into the soil from the air a specially large quantity of nitrogenous food and of humus-producing materials, without wasting any of the manure that was applied to it, the method would seem to be a peculiarly happy device for applying fertilizers economically. It may well be asked whether it would not often be best, in cases of green manuring, to encourage the growth of the green crop by dressing it moderately with manure.

In some of our Southern States, the annual, crimson clover is grown occasionally on soils which are too light for ordinary clover. When once fairly started, the crop does well on non-calcareous, sandy or light clay soils, though it is somewhat uncertain since the newly germinated plants are easily "burnt off" by hot sunshine. As far north as Delaware it can be grown either as a summer crop or as a winter crop which shall cover the land during the autumn months. In the latter case it is sown in late July or in August. In an experiment described by the Delaware Experiment Station, a single dollar's worth of crimson clover-seed to the acre, sown under Indian corn at the time of the last cultivation, gave a green crop which weighed 8 tons and 600 lb. as it stood in blossom in the field in the first week of the following June. It was ploughed under on June 5, and Indian corn was planted upon it on June 7, and there was obtained a yield of 48 bushels of shelled corn to the acre against 24 bushels of corn harvested from an adjacent acre which had borne tomatoes in the previous year, and which was dressed with 100 lb. of nitrate of soda as a preparation for the corn. (Allen.)

Grain Fed by Legumes.

There are several very old European methods of growing grain after leguminous plants which depend absolutely on the idea of green-manuring. Thus, Gasparin reports that on soils and in situations suitable for growing lupines he has seen that plant habitually made the basis of a succession of crops of cereal grains by simply sowing its seeds immediately after the grain harvest and ploughing under the green crop a short time before seeding the land with the next crop of grain. In a similar way, irrigated land in Southern Europe may be well manured by growing beans upon it as a stolen crop and plowing the plants under in October, when they are in blossom, as a preliminary to the sowing of wheat. A method of manuring for barley formerly practised in Western Germany was to harrow lightly the stubble of winter wheat, or rye, immediately after the harvest, and to sow vetch seeds very thickly. The young vetch-plants were dressed with gypsum, to encourage luxuriant growth, and the green crop was finally ploughed under in late autumn, as a preparation for barley, which was sown in the spring. The barley obtained in this way is said to have been of excellent quality and exceptionally heavy.

Another method, sometimes practised in Northern Ohio, is to leave the second growth of clover lying upon the field during the winter, as a heavy mulch, care being taken to comb down the knee-high crop with a smoothing harrow, just before cold weather sets in, so that the plants may all lie down in one direction, viz. that in which the plough will eventually be drawn. Land thus mulched dries out somewhat slowly in the spring, and there may be some delay before the breaking up of the sod can be proceeded with; but by using a plough upon the beam of which a skimmer or "jointer" (a small ploughshare) has been set, even a mass of clover-plants so heavy that they represent a crop of two tons of clover hay to the acre can be turned under without much trouble. (Terry.)

Spurry for Green Manuring.

Spurry (Spergula arvensis, and variety maxima) is another plant which has sometimes been used for green-manuring in some of the moister parts of Europe. It grows rapidly and may readily be interpolated as a stolen crop between two successive crops of rye. It is regarded as an ameliorating crop, like clover, and this popular impression is supported by the experiments of Voght, who by growing and ploughing under three successive crops of spurry in one season was enabled to grow subsequently a heavy crop of rye, and afterwards a crop of potatoes on the land thus prepared. Voght estimated that the fertilizing effect produced by his spurry was equal to that of 4.5 tons of farmyard-manure. It needs to be said, however, that in spite of much farm experience which seemed to indicate that spurry must be able in some way to get free nitrogen from the air, there are scientific experiments by Schloesing and Laurent which signally failed to confirm this idea. In so far as these observers could determine spurry was no better able than oats, mustard or cress were to fix free nitrogen.

How to Plough Green Crops.

A common method of facilitating the operation of ploughing under a green crop is to fasten to the plough-beam near the standard one end of a short heavy chain and to attach the other end of the chain to the whiffletree of the off horse, so that the loop of chain in passing over the ground may drag the plants towards the furrow in such manner that they can be handsomely covered by the furrow slice. In case the plough is drawn by oxen, the outer end of the chain may be fastened to a stick which has been bolted into the plough-beam for this purpose. Some farmers have insisted that it may be well in certain cases to pass a roller over the green crop in order to crush down the plants before ploughing them under, while others maintain that rolling is not necessary. In case a green crop has been grown late in the season, the ploughing of it may well enough be postponed until just before the ground freezes, and if this be done there will be less trouble in turning under the frozen and fallen crop. In some cases the ploughing might even be put off until the next spring.

Green Manure a Source of Humus.

It is to be noted, that by ploughing under a forced clover-crop, an abundant supply of organic matter may be added to the soil through the intervention of purely inorganic manures, such as guano, or superphosphate, or wood-ashes. In view of this fact, one of the objections most commonly urged against the use of the inorganic or mineral fertilizers falls at once to the ground. It has been suggested repeatedly, both by systematic writers and by practical farmers, that the long-continued use of inorganic manures must inevitably impoverish the soil, since in using them continually no supply of humus (such as is given in barnyard-manure) would be brought to the soil. But, manifestly, it is an easy matter to raise a crop of humus once in a while for the land, and upon the land, whenever it may be needed; and this may be done very conveniently by growing the green manure in late summer, after an early crop of grain, or the like, has been harvested. There would be no need of giving up the use of the land for an entire season. So far from the fertilizers used to force a clover-stubble being wasted, the sum total of plant-food in the soil is actually increased by whatever the clover has taken from the air.

Of course, in a dry grazing country like New England, where the "fall feed" for pastured cattle is no small item to be taken into consideration, the ploughing-under of a forced clover-crop would seldom be justifiable. The green crop would be fed out, either green or dry, to cattle, who would return dung to the land. Perhaps the land would not be so well manured in this way for the time being, but the advantage to the farmer would nevertheless be greater in most cases; for, in spite of the cost of harvesting the forage, of carrying it to the cattle, and of carting out and spreading their manure, it would still be true, in the long run, upon a well-conducted farm, that the farmer will get two profits, — one from the animal increase or other product obtained by using the fodder, and another from the manure which the fodder has produced.

Rather than plough under the clover, it would be better, on many farms, to mow it once for hay, and again for seed to be sold. For the clover-roots alone would be equivalent to a considerable quantity of manure, and with the money got by selling the clover-seed there might be bought a store of cotton-seed-meal, corn-meal bran, or malt-sprouts, wherewith to produce dung. It is a fact, as will be explained hereafter, that animal excrements act as manure more quickly, more powerfully, and more assuredly, than the plants which have produced them can.

Generally speaking, all green crops are thus fed out nowadays, and it seldom happens that a crop is ploughed under if it be thrifty. Nevertheless, it may sometimes be well to force old sod-land in the spring, in the manner just now indicated, as a preliminary to planting corn, provided the land is well suited for the purpose. So, too, when Indian corn is grown after winter wheat, one way of proceeding is to sow 10 or 12 lb. of clover-seed to the acre upon the wheat in the spring, and to plough under the clover the next spring, in the latter part of May, by which time a vigorous growth will have started, and immediately to plant corn upon the inverted sod. There must always be exceptional cases, as of fields far from the homestead, where green-manuring may be advisable. And in cases where a crop has grown so feebly that it promises to be hardly worth the trouble of harvesting, it may sometimes be good practice to plough the crop under, out of hand. In such event, where the amount of herbage to be ploughed under is but small, there need be little or no delay in sowing seeds upon the land for another crop, especially as regards some kinds of crops; but when a heavy green crop has been turned under, time enough has to be allowed, in many cases, for the buried plants to decay before the seeds for the next crop can be sown, lest they, too, be destroyed by the process of putrefaction. For example, it was a rule among Saxon farmers, that, when rape-seed was to be sown in autumn, after clover, the latter could not be mown twice or thrice during the course of the summer. On the contrary, the stubble was ploughed under after the first cutting of the clover, and left to decay until September, when the rape-seed was sown.

Green Manure may Decay Slowly.

A moment's consideration of the familiar method employed for preserving fodder in silos will teach that a green crop, which has been ploughed under, can hardly be expected to decay very rapidly beneath its covering of earth, unless the conditions should happen to be specially favorable for decomposition. For rapid decay, there will be needed warmth and a fair amount of moisture, as well as considerable supplies of air, and the presence of an abundance of the micro-organisms proper for fermentation. In case the earth were so compact or so wet that air could not gain access to the buried plants, they would undergo comparatively little change, and be preserved as ensilage is. But, under favorable conditions, the buried plants will decay, with evolution of ammonia, much as a heap of green weeds would, above ground. Dehérain, operating in France on "permeable land," noticed that vetches and mustard, ploughed under in November, did not decay rapidly. A fortnight or three weeks after burial, the leaves and stalks of the plants were still green, though soft and withered; but soon afterward they blackened, and began to exhale ammonia in the fields that were moderately moist. After 2 or 3 months, however, it was hard to discover any remains of the plants.

Green Manure versus Fallows.

In general, it may be said that the practice of green-manuring militates strongly against the system of allowing land to lie in naked fallows.

Beside the opportunity afforded for nitrification, one chief merit of fallowing was found in the power it gave the farmer of destroying weeds on land which had become insufferably foul. Long before fallows were discarded in countries the agriculture of which is somewhat advanced, it had come to be a tenet of good practice that the fallow land must be ploughed repeatedly, so as to bury the half-grown weeds as often as a new crop of them had sprung up. The custom was to apply manure to the fallow land, late in the spring, and when this manure was ploughed under, many weed seeds germinated, as a matter of course, and weeds grew in great abundance. But most of these weeds were destroyed, on again ploughing the land. Thus the practice of green-manuring is in some sense an outgrowth from the system of fallowing.

Fallows were at one time defended, it is true, upon the ground that all land needs rest occasionally. But, as was just said, long before the practice fell into disrepute, it had become a feeble system of green-manuring, in which the weeds constituted the green crop. But, manifestly, if it is proposed to practice green-manuring, it will be best to practice it thoroughly. If a field is to be given over for a season to the production of green manure, economy demands that, by means of some appropriate seeding, it shall be made to produce a fair crop of the desired manure. And it is easy, by means of light dressings of artificial fertilizers, to grow several tons of the green crop, and so to plough in a mass of fertilizing material, which, in so far as mere weight goes, will compare favorably with a moderate manuring with dung.

Even if the destruction of weeds is the thing specially desired, it would be best to grow a succession of green crops throughout the summer, one after another, upon the inverted sod of the previous tender plants, and it might often be well to let cattle or sheep run upon each of these short green crops a week or so before ploughing them under, in order that some of the best of the forage should be eaten off. Buckwheat may be grown in this way to the extent of three crops in a single season, and since the plants stand close together, and occupy the land completely, weeds have little chance to thrive. It is said, moreover, that buckwheat, sown very early in the season, "runs to leaf," and produces much stalk and very little grain.

Mustard as Green Manure.

White mustard appears to be particularly well suited for use as green manure, because no more than 6 or 8 weeks are needed for it to grow. Two crops of it may be ploughed under in a single season, and time enough still be left for seeding down the land to grass or grain in the autumn. In many cases, a peck of seeds to the acre is thought to be enough, and only a light ploughing is needed when the crop is to be buried.

Several English farmers have urged that, no matter whether the year be wet or dry, the foulest fields of strong land may be cleaned in a single season, and even couch-grass be completely destroyed, by growing three successive crops of white mustard upon the land, and ploughing them under. In case the land is very foul, it is thought best to plough under all the herbage, because the second and third crops will be heavier, in this case, than if the previous crop had been eaten off; but if the field is moderately clean, sheep may be permitted to eat off the bulk of each of the crops. A dressing of 100 bushels of lime (slaked with brine) to the acre, applied after the first ploughing, has been found useful. About one-third of a bushel of mustard seed is sown to the acre. The plants are ploughed under just as they are bursting into flower, and pains are taken to re-sow the land upon the fresh furrow the very day of the ploughing, in order that the smothering power of the new crop may be brought into action before any of the half-dead weeds shall have time to revive. It is said that three successive crops of mustard will not only check weeds, but leave the soil in a condition almost as good as if a medium dressing of farmyard-manure had been put upon it. It is said to be well to sow a small quantity of nitrate of soda upon the first crop of the green manure, in order that it may grow thick and strong, and be the better able to smother couch-grass and other weeds. One cwt. of the nitrate to the acre has been known to double the first crop of mustard, and to increase the succeeding crops also, to the manifest improvement of their smothering power. Some farmers, instead of ploughing under three crops of mustard, prefer to grow vetches, annual clover, or some other forward crop, in the spring. After this crop has been fed off to sheep, there will still be time to get two crops of mustard, to be ploughed under or eaten off, according to circumstances.

Marshall tells of an experiment in which rape-seed, sown late in July, in Southern England — on land which was to be sown in the autumn with wheat — gave excellent pasturage to sheep, which not only ate the rape-plants with avidity, but preferred them to turnip-tops.

Rib Ploughing for Burying Weeds, etc.

There was an old English system of ploughing, called "ribbing," that deserves to be studied anew in connection with the subject of green-manuring. In ribbing, the plough was made to turn up a thin slice of sod, and lay it over flat, face downward, on the adjoining surface of undisturbed sod.

At a proper distance from this first furrow, i. e., at the next furrow but one to it, a second slice of sod was inverted upon the strip of undisturbed sod that had been left to be buried; and so the entire field was thrown into a system of low ridges and shallow furrows. The herbage was in this way completely buried, though only half the surface of the land had been actually ploughed, and that with light labor.

In the old English practice, the sods were left thus buried face to face until the grass and roots had rotted, when the entire surface of the land was broken up by means of a heavy harrow, or by ploughing the field across.

It seems probable that this method might sometimes be applied with advantage upon land foul with weeds, in cases where a couple of crops of green manure were to be grown in a single season. The first crop of green manure might be ribbed while the plants were young, and the second crop sown upon the ribs without disturbing them. Finally, the last crop would be ploughed under crosswise.

Perhaps the method of ribbing could be used also for the improvement of old pastures, run out to white-top or other useless grasses. For, with a comparatively small expenditure of labor, it would be possible, in many cases, to destroy the old grass, and to bring the land into such shape that white clover and fine-top, and June-grass or orchard-grass, would flourish upon it, when simply sown on the ribs without further tillage, perhaps even without any other manure than the rotting sod would give.

Green Crops shade the Land.

There is one merit in green manuring that has been strongly insisted upon by some writers; viz., that by shading the ground the crop brings the soil into a favorable condition of fermentation, whereby useful chemical actions are induced and maintained, at the same time that good physical conditions are insured.

It is undoubtedly true, as regards the surface soil, that shade does act something like a mulch to keep the land open and mellow, as well as to protect it from the baking influence of the sun and the formation of crusts by beating rains. So many weeds are choked withal by the green crop, that the land may be cleaned thereby to an appreciable extent. But, as will be shown hereafter, the very crops which shade the soil best, and keep its surface mellow, are precisely those which pump the largest quantities of water out of the lower layers of the soil, and tend to leave it so dry that succeeding crops may be injured. It is on this account that green-manuring is often inadmissible on land which is to be sown with grain in the autumn, for it might readily happen that so little moisture would be left in the soil that the seeds could not germinate nor the young grain-plants grow. Moreover, the good effects of shade are in no sense a peculiarity of the process of green manuring. They will be felt just as strongly when the crop is to be harvested and used for fodder, as when it is to be ploughed under.

No matter how important the shading of land may be considered, there is still abundant evidence to show that the ploughing-under of green plants is an effective method of fertilization. Thus, Schober, on harvesting a crop of turnips that had been dressed with farmyard-manure, removed both tops and bulbs from one-half the field, while upon the other half of the land the tops were ploughed under. The next spring, oats were sown upon the entire field, and there was harvested from the land —

Where the turnip-tops were left	2,300 lb. grain and	3,700 lb. straw, etc.
Whence the turnip-tops were taken . . .	1,800 " "	2,370 " "
Gain from the turnip-tops	500 " "	1,330 " "

Hlubeck divided a bean-field into two equal parts, ploughed under the crop on one-half the field, and carefully removed both crop and roots from the other half. Wheat was then sown, and it yielded 33 measures of grain where the land had been fertilized by the bean-plants, and only 22 measures where the bean-crop had been removed.

Wollny divided a field into plots, each of 4 square metres, and left some of these plots fallow, while several kinds of plants proper for green-manuring were grown upon the others. When the plants were in flower, one plot of each kind was ploughed under, while another similar plot was mown, and the product carried to a fallow plot, there to be ploughed in. The stubble plots were ploughed, also, and the next year peas were sown upon the land. Comparisons were thus made as to the fertilizing effects produced by roots left in the land, tops carried to the land, crops ploughed under, and bare fallow. The results of these trials are set forth in the following table : —

Kind of Plant.	There was ploughed into the land	Grain Grm.	Straw Grm.
White Lupines.	I. Roots and stubs	877	1,602
" "	II. The entire crop	1,283	1,470
" "	III. Plants from I	1,443	1,880
White Mustard.	I. Roots and stubs	1,011	1,223
" "	II. The entire crop	1,192	1,327
" "	III. Plants from I	1,491	1,668
Vetches.	I. Roots and stubs	863	1,066
"	II. The entire crop	1,145	1,126
"	III. Plants from I	1,439	1,603
Buckwheat.	I. Roots and stubs	973	1,208
"	II. The entire crop	1,006	1,063
"	III. Plants from I	1,135	1,429
Fallow		983	1,237

The merits both of fallowing and of green-manuring are evident from these figures, for the green tops ploughed into land that had been refreshed by fallowing, and from which nothing had been taken by the plants, gave better results than were got on the plots that were given over to green-manuring alone.

Lupines as Green Manure.

The ploughing under of lupines as a means of fertilizing land is a practice of the highest antiquity. Pliny said of it, in his time, "It is universally agreed by all writers that there is nothing more beneficial than to turn up a crop of lupines, before they have podded, or else to cut them and bury them in heaps at the roots of trees and vines." The white lupine has, in fact, been used for green-manuring, in Italy and in Southern France, from the earliest times, and it is still habitually grown there, in some sandy regions, to be ploughed under, as a forerunner of winter rye, and even of winter wheat. Efforts were made to introduce it into Germany near the beginning of the present century, but it gained no very firm foothold at first, because animals refused to eat the plant, and because it often failed to ripen its seeds. Gradually, however, the white lupine, which had been used solely for green-manuring, came to be replaced, in Germany, by the yellow and the blue lupine, which are suited by the climate, and which, even when not ploughed under, work very decidedly to enrich sandy soils. Both these crops, but especially the yellow lupine, have the very great advantage over the white-flowering plant, that they can be used, either green or dry, as fodder, especially for feeding sheep.

Since the middle of this century, they have been extensively grown in several sandy districts of Germany, and the more succulent yellow lupine, in particular, is esteemed to be a blessing upon many poor, light, sandy soils, in situations where hardly any other leguminous plants can live. Land that formerly yielded nothing but miserable crops of rye, and where even buckwheat was apt to fail in dry seasons, now gives profitable crops of several kinds, thanks to the introduction of the yellow lupine in the courses of rotation. The lupine plants are said to grow to a height of 3 or 4 feet, even on the poorest soils, in case any rain falls to eke out the winter's supply of water.

Some farmers have reported that, if yellow lupines are mown for hay before the middle of July, so many new shoots will spring up from the roots that the land will be covered with a new crop in the course of three or four weeks. This second crop may be mown green, or left to ripen seeds, according as the first crop was mown late or early. Ordinarily, the young lupine-plants are fed off to sheep, or the mature crop is mown and dried to hay, upon racks, as beans are; though, inasmuch as the hay and the seeds obtained from it are somewhat liable to poison animals, and are bitter and repugnant to most animals until they have become habituated to their use, there is less incentive to harvest the crop than would otherwise be the case. Hence, a not uncommon method of procedure is to sow the yellow lupines in June, to roll down the crop when it is in full flower and the first pods are beginning to show, and to plough the plants under. Some weeks after the ploughing, rye is sown, and better crops of rye have often been got in this way than when the land had been dressed with farmyard-manure. Sometimes the bulky lupines have to be mown before they can be ploughed under, and some farmers have even taken the trouble to rake the mown plants into the furrows.

In Southern countries, the lupine is not winter-killed unless the thermometer falls below 7° F. (Gasparin), and in Italy it is grown as a stolen crop, on fields where grain has just been harvested, and is ploughed under the next spring in time to permit the land to be prepared for the crop of that year. But in North Germany the land has to be given over to the lupine crop during the entire spring and summer.

Latterly it has been urged that it will be best to plough under the crop, not at the moment of flowering, but as late as may be possible, because it has been observed that the largest quantity of nitrogen is taken in from the air after the time of flowering, and before the seeds have become fully ripe.

The lupine has several peculiarities which specially fit it for use as green manure. It appears, indeed, to be by far the best plant for the purpose which has yet been discovered. It grows rapidly, even on sandy soils, and sends its roots deep down into the earth; it stands drought well, and is said to be very little troubled by insects; it is leafy and voluminous, so that it shades the ground abundantly, and yields an enormous burden of organic matter. And, most important of all, it supports microscopic fungi upon its roots, which take nitrogen from the air, as has been set forth in the chapter on Symbiosis.

Lupines grow well on sandy and loamy soils, even on loams that are tolerably rich in humus or clay. They do not succeed on cold or stiff or wet land, or on very rich humus, or on calcareous soils. But it is now well known that the prosperity of this plant depends chiefly on the presence, upon its roots, of a parasite which has the power to take nitrogen from the air, and in case the lupine-crop should not succeed, when grown in a new locality, the first thing to be done would be to scatter upon the new land a quantity of soil taken from an old lupine-field, in order to bring in the root-bacterium. Acting on this idea, Budrin has obtained excellent crops of lupines on light, sandy loams. By using composts also, he got remarkably fine crops; and he urges that, by means of compost, wood-ashes, and ground phosphate-rock, lupines may be grown on the sandiest soils, provided they are not so situated that a short drought would ruin the crop.

Effects of Green-Manuring.

The following examples of results obtained by growing rye, after green-manuring with lupines, have been copied from Heiden. One-half of a field was sown with 60 lb. of lupine seeds, and the other half was left fallow. When the lupines were well grown, the whole field was ploughed and sown with rye. In one case, there were harvested, in pounds, the following amounts: —

	Grain.	Straw and Chaff.
After the lupines	532	1072
After the bare fallow	232	656

In another case, —

After lupines	400	609
After bare fallow	245	503

In other cases, where the stand of lupines was light, —

	Grain.	Straw and Chaff.
After lupines	270 and 259	498 and 542
After bare fallow	216 " 191	423 " 388

In another case, rye was grown on a sandy soil after yellow lupines, on plots of 24 square rods, as follows: —

	Grain.	Straw and Chaff.
I. Where lupines were ploughed in	96	205
II. Where lupines were mown and carried to III.	64	130
III. Where lupines from II. were ploughed in	66½	136
IV. After bare fallow	56	114

Examples of Green-manuring.

Some American examples of green-manuring have been reported as follows. Plough the land in June, harrow in buckwheat, and plough the buckwheat-crop under in August, or before the seeds begin to ripen. Finally, sow winter grain in the autumn. It is said to be a good plan to lime the land after ploughing in the buckwheat; and, as a general rule, it is thought to be well, after a green-manuring, to apply lime at the rate of some 25 or 30 bushels to the acre. If the crop of green manure be large, the plants should be rolled heavily before ploughing them, so that they may be fully covered with earth, and care should be taken to bury them deeply, so that enough moisture may be retained to insure speedy decay.

Another way of proceeding is to sow white turnips after the buckwheat above mentioned has been ploughed in, and to plough under the turnips, in their turn, in the spring. The turnips have the merit that they will continue to grow in the autumn after the early frosts. In some seasons they will grow a good deal at that time. Still another way is to sow rye on the buckwheat-sod, and to plough in the rye the next May, when it is 3 or 4 feet high, and plant Indian corn upon the land.

P. Wagner sowed peas and vetches in August for three years, on land poor in nitrogen, but which was heavily dressed with potassic and phosphatic fertilizers, and carefully tilled. He ploughed under the luxuriant green crops late in the autumn, and sowed summer rye upon the land the next spring. During the three years, the green crops brought to the land from the air, in the stems and leaves alone, some 200 kilos of nitrogen to the hectare, and the rye harvests were increased thereby to the amount of 3,300 kilos of grain and 7,500 kilos straw to the hectare.

In case a crop has been removed from the land so late in the season that turnips cannot be grown upon it for sale, rye may be sown, either to be pastured in late autumn and early spring, or to be cut green in the spring, or to be ploughed under at that time, as circumstances may dictate. Rye will grow freely in warm autumn weather, especially on moist low-lying land, and will not only check the growth of weeds, but pick up the nitrates in the soil, and prevent them from being washed away by the rains of autumn and spring. In so far as this saving of nitrates is concerned, it will usually be true that the richer the land the greater will be the need of keeping it covered with growing crops during autumn, winter, and spring, in order to prevent leaching by rain. In summer, as has been shown, comparatively little water soaks out from the majority of cultivated fields.

One Trouble with Green-manuring.

It is commonly taught that green-manuring is specially adapted to sandy soils in climates that are rather dry, though it has often been employed with advantage on heavy land. But there is one danger that needs to be kept in view and guarded against when possible. On light land, serious trouble might ensue if a drought should set in immediately after a green crop had been ploughed under. For, unless there be moisture enough in the soil to rot the buried plants, the field would be left in a bad condition. In case of need, the land should be rolled after the ploughing, and it might even be subsequently harrowed lightly, i. e. cultivated a little at the surface, to prevent the moisture from drying out from the rolled earth.

It has even been noticed, on light sandy loams, that strawy horse-manure may sometimes give lighter crops than cow-manure, because of too much lightening up of the soil. That the converse of this is true, as a general rule, is well known, horse-manure being specially esteemed for cold, heavy soils.

Manifestly, green-manuring is a method of fertilization that needs to be used with care. It will probably serve a better purpose in districts where the soils are calcareous than in regions of barren silicious gravels, like the vicinity of Boston. But it will always be safest, in the beginning, to experiment with the process cautiously before subjecting one's self to expensive risks. If the condition of the soil is favorable as regards moisture and texture, green-manuring might be a valuable resource. But if the conditions are unfavorable, the ploughing-in of green crops might do more harm than good, and involve the operator in wasteful expenditures.

After all has been said that can be in favor of the system, it still remains true that, excepting old sod-land, green-manuring is a resource for the landscape gardener rather than for the farmer. It may serve a good purpose in cases where waste pieces of land need to be beautified quickly and at small cost; but under the arrangements that commonly exist upon farms, nowadays, it will usually be found more economical, as has been said, to harvest any green forage that may be grown, and to feed it out to animals whose dung will be returned to the land at some appropriate moment in the course of a judicious rotation of crops. For the owners of most farms, especially if their land be fertile, it is from the scientific point of view, and not from the practical or economic, that green-manuring is to be regarded as interesting and philosophical.

Transported Green Manure.

A practice akin to green-manuring, and probably an outgrowth from the Roman custom of dressing vineyards with green plants, is seen at the south of France — in certain localities that are too dry to admit of growing forage for maintaining animals — where the vineyards are mulched and manured with the hay of sedges and rushes, and other swamp-plants, which are mown on land that is too wet to be cultivated. Sometimes the hay is transported to distances as great as 25 or 30 miles (Gasparin). So, too, in Ireland, fern cut in the autumn is sometimes left to rot upon the beds where potatoes are to be grown next year, and good crops of tubers are obtained. (A. Young.)

Straw of Grain.

The value of straw as manure is evidently less than that of green crops; for there is necessarily less nitrogen in straw, and a smaller proportion of those inorganic matters which are valuable, than there is in young herbage. It is known that, as the seeds of a plant ripen, most of the phosphoric acid and nitrogen, and much of the other specially useful ingredients, pass up out of the stalk of the plant into the seeds.

According to Stoeckhardt, 2,000 lb. of absolutely dry straw contain —

	Wheat.	Rye.	Barley.	Oats.
Organic matter	1,920	1,940	1,910	1,900
Nitrogen therein	8	6	6	6
Inorganic matter	80	60	90	100
Potash and soda	12	11	24	28
Lime and magnesia	6	7	10	10
Phosphoric acid	4	2¼	4	3
Silica	56	36	46	50

Of course, these numbers are mere approximations to an average. In special cases, where the crop has been heavily manured, or the season has been moist, though not over wet, the amount of nitrogen may be twice as large as is here given. It is to be observed, also, that the figures refer to straw dried at the temperature of boiling water. Ordinary straw contains some 8 or 10 or 12 % of moisture.

It is a matter of experience that the nitrogen in straw is less efficient than that in green vegetable manner. In fact, the chief value of straw, considered as a fertilizer, must be attributed to the ash-ingredients which are contained in it; though the mere organic matter of straw is useful also in that it serves as food for the microscopic organisms which bring about decay and fermentations.

Some interesting Saxon experiments bearing upon the value of straw are quoted by Stoeckhardt. A farmer manured his land for several years with a couple of swamp-plants, — one part of the land with the cat-tail and the other part with the large bulrush. He found that, while the cat-tail was a really useful manure, the bulrush had scarcely any fertilizing power for his land.

On subjecting samples of these plants to analysis, there were found in 2,000 lb. of the dry —

	Cat-tail. lb.	Rush. lb.
Organic matter	1,900	1,960
Ash-ingredients	100	40
	2,000	2,000
Nitrogen	12	11
Potash and soda	22	1+
Lime and magnesia	32	8
Phosphoric acid	5½	2
Silica	8	22

Since the proportion of nitrogen and of humus-forming ingredients is nearly the same in both plants, and the chief difference is found in the proportion of alkali compounds and phosphoric acid, it is fair to infer that neither the nitrogen nor the humus-formers are of so much value in these plants as the inorganic materials.

Straw a Salable Crop.

Reference will again be made to straw, under the headings, Dung, Urine, Compost, and Potash. Properly speaking, however, straw belongs among foddering materials, and is in most situations worth more as fodder than it is worth as manure. Moreover, in many localities straw is worth still more for various purposes outside the farm than it is worth as fodder and manure. Formerly, when there were no means of compressing straw for sale, or of transporting it when compressed, it was almost everywhere regarded as an important resource for keeping up the fertility of farms. But in modern times there are numberless situations where straw is as readily salable at a profit as any other crop, and in such cases, i. e. wherever there is a market within reach, it is evident that straw should be sold as such, and the price of it expended, if need be, in buying some other form of manure. For packing fragile articles, and for bedding men and animals in cities, straw usually commands a price which takes it out of the category of manures. It should be seldom, if ever, thought of as a manure nowadays in regions where it is salable.

Sea-weeds.

Several sea-plants, or, as the common expression is, sea-weeds, are largely used as manure upon our own sea-coast and upon the coasts of Great Britain and France. These sea-weeds are of various kinds, but in New England the farmers usually divide them into three general classes, viz. eel-grass, rock-weed, and sea-manure.

Eel-grass (Zostera marina) may first be treated of, not, however, because of its value as a fertilizer, for it is the least valuable of all the sea-plants. On the contrary, it is chiefly interesting because it so well illustrates what was just now said of straw; viz., that the mere fact of a thing's being of organic origin does not in any way prove that it has much value as a manure.

Eel-grass is, in fact, a sort of flat straw; it contains some nitrogen (about 1.33 %), and a large proportion of what might be supposed to be humus-forming ingredients. More than 70 % of the air-dried eel-grass is organic matter. But, taken by itself, the eel-grass has little or no fertilizing power. It will hardly rot anywhere, either in the ground, in the hog-sty, or in the manure or compost heap. It is a distinctly inconvenient thing, moreover, to have in the way of the ploughshare or the dung-fork. It has long stood as a kind of reproach among the vegetable manures, much as leather-scraps stand in the list of animal products. For mulching, for covering bins or piles of roots — as a protection against frost, mouldiness and decay — and for banking up, in autumn, around stables, greenhouses, cisterns, cellars, and pumps, eel-grass has been found useful, and this is about all that could have been said in its favor until very recently. Considered as a manure, it was rejected by the farmers long ago. It had been tried and found wanting by numerous generations of men.

Still, on analysis, it appears that eel-grass contains a considerable proportion of fertilizing matters, and there can be no doubt that it will be found amenable to proper treatment, and will eventually be prized as a manure.

Beside 1⅓ % of nitrogen, air-dried eel-grass contains 1 % of potash and 0.25 % of phosphoric acid. The ashes of eel-grass contain 7 % of potash and 1½ % of phosphoric acid, which is about as much as is contained in ordinary house-ashes, from wood fires.

The trouble with eel-grass is, as was said before, that it will not rot in the soil. It must be coerced in some way in order to make its fertilizing constituents available for crops. It might be burned, for example, to ashes, in order to get the potash and the phosphoric acid; or, much better, the organic matter may be disorganized by composting the grass with lime or with rock-weed. That is to say, the eel-grass may either be thrown into heaps, with layers of lime interpolated in order to reduce the resisting tissue to a manageable form; or it may be built into a heap, layer by layer, with fresh rock-weed or sea-manure, and so subjected to destructive fermentation.

Sea-manure Proper.

The really fertilizing sea-plants, i. e. those which are esteemed as fertilizers, belong to the class of Fuci, including the broad kelp or devil's apron, ribbon-kelp, rock-weed, and carrageen, or to the class of Algæ. All these plants are highly mucilaginous, and they contain much nitrogen. They might almost be compared to flesh, without going very far wrong. When fresh, these plants contain a very large proportion of water; hence, when they once begin to decay and become disorganized, they melt down into a very small bulk, and seem almost to dissolve away. In this process of dissolution, most of the nitrogen originally contained in the sea-plants goes to waste, and a considerable proportion of their ash-ingredients also may soak into the earth. Hence, practical men object to leave sea-manure lying in heaps at the heads of beaches for more than a few hours. It is because of this rapid depreciation that farmers very much prefer to collect sea-plants which have just been torn up by storms, or to pull or cut rock-weed directly from the rocks, rather than to cart away sea-manure which has once before been thrown up by the waves and then washed away again for a time, after it had begun to decay.

From the fact that the tender organic matter of the sea-plants decomposes so easily, and that the plants themselves have no power of absorbing liquids such as is possessed by straw and leaves, there can be nothing gained for the sea-manure, either by composting it or by allowing it to ferment before it is applied to the land. It may, however, be used as a sort of yeast to induce the fermentation of eel-grass or peat; i. e. to improve these materials. Practice accords with theory in this particular, sea-manure being usually either ploughed in green or spread upon the land as a top-dressing in as fresh a state as it can be procured.

In either case, the sea-manure decays very rapidly, except in times of drought, and produces its chief effect upon the first crop. When ploughed under, it tends to make the soil open and friable. The rapid action is in this case one of unmitigated advantage, for wherever sea-manure is to be had at all, it can generally be obtained one year nearly as well as another, and it may therefore be supplied to the land as often as is desirable.

It is an easy matter, withal, for the farmer to keep a large stock of cattle upon the grass or other forage which the sea-manure nourishes, and so to supplement that kind of manure by the dung of cattle thus kept. But the stable-manure, though helpful, is not essential. There are several islands on the coast of France where sea-weeds and the ashes of dung are the only manures employed upon the farms. Cattle are kept, indeed, in large numbers, but the dung is all dried and used for fuel.

On the island of Jersey, in the English channel, the sea-weeds thrown ashore by the winter storms are esteemed to be an excellent application for grass. Herbage of excellent quality is produced, and cattle feed with avidity in pastures to which sea-weed has been applied. It is used there also, together with farmyard-manure, on rich land for parsnips, and sometimes for mangolds and Swedish turnips, though not for potatoes, to which it is said to impart a disagreeable flavor. For parsnips, a good coating of fresh sea-weed is spread upon the land in autumn or winter, and ploughed under 2 or 3 inches deep; and in the spring the land is dressed with 20 or 30 tons to the acre of farmyard-manure, which is deeply buried with a trench plough.

Here in New England there is abundant evidence of the great value of sea-manure. If we throw out of consideration some isolated tracts of rich calcareous land, as in Aroostook County, and the intervale farms of the Connecticut River and its tributaries — which are practically farms manured by way of irrigation — as well as those farms which depend upon the manure derived from great cities, and perhaps some farms upon Buzzard's Bay, Long Island Sound, and the coast of Maine, that are based upon fish-manure of one kind or another, the only really fertile tracts in New England are to be found back of those sea-beaches upon which an abundant supply of sea-weeds is thrown up by storms.

The strip of country behind Rye Beach, in New Hampshire, comprising the towns of Rye, Greenland, and Northampton, affords a striking example of this fact. Abundant crops of hay, and (in former times more than now) of potatoes, are there grown and sold year after year, while the country remains fertile and fortunate. So, too, in Scotland and Ireland, in places where there is an abundant supply of sea-weeds, it has sometimes happened that land has been cropped with wheat and potatoes alternately for a long series of years, without suffering deterioration, and without any diminution of the quantity of the produce.

Sea-manure vs. Drought.

It is noteworthy that grass-fields dressed with sea-manure remain green throughout the summer droughts, at times when the scantily manured fields of the interior are brown and parched. It is a general rule, that highly manured land is better able to hold and to supply water to crops than unmanured land is; and it is to be presumed, also, that the constituents of the sea-manure may act to improve the capillary power of the soil. It is true, more-over, of soils that are kept in good tilth, and well stored with easily assimilable supplies of plant-food, that the roots of crops will penetrate far below the surface, and thus be in position to get both water and food from a much larger reservoir of these commodities than can possibly exist, in times of drought, in the shallow surface soil of fields that have neither been tilled nor manured.

At Rye Beach, the use of the sea-manure extends some 8 or 10 miles back into the country, and to a less extent even to 12 or 14 miles. The high estimation in which sea-manure is held in places where it can be got is well illustrated by an observation of Arthur Young. At a locality on the west coast of Ireland he found that the peasantry esteemed one load of sea-manure to be worth at least 6 loads of dung. "It is so strong that they depend entirely on it, and will not be at the trouble to carry out their own dunghills. On the shore, they actually let their dunghills accumulate till they become such a nuisance that they move their cabins in order to get from them." So, too, it is a matter of history that on the Orkney Islands farmyard-dung was formerly considered so inferior to sea-weed as manure, that no one used it. It was allowed to accumulate in heaps, or was carried to some convenient place where it could be put into the sea. It has been said in 1874, that within the recollection of living men the tenants upon one of the islands were bound to clear out the laird's dung-courts once a year and carry the stuff to the sea-beach, where it was washed away by the tide. One farm was thought to possess a great advantage in that the dung could be thrown from the cow-stables directly into the sea. (Pringle.)

Sea-Manure is Watery.

It is the enormous amount of useless water which has to be transported in the sea-weeds that practically limits their use to the immediate vicinity of beaches; it explains, too, the popular impression that this kind of manure is transient in its effects, and needs to be frequently renewed. For in view of the large proportion of water in sea-manure the proportion of other things that are contained in it must be small, and the land is really manured very lightly in using it, although the farmer may haul and distribute a great mass of bulky material.

It is because of its containing so much water, doubtless, that in a cold country like Sweden the peasants, as noticed by Linnæus, do not put sea-manure in the fresh state upon wet soils. It would be slow to ferment and decay there.

One advantage which the sea-manure shares with the commercial fertilizers is its entire freedom from the seeds of weeds, the spores of fungi, and the eggs of insects. It is a comparatively easy matter to keep a farm clean and in good heart when there is no innumerable host of weeds to overrun the land, to dissipate its moisture and sap its strength, and to distract the farmer and hinder him from tilling the land as he would like to do. According to Evelyn, "dung is the nurse of vermin."

The growth of sea-weeds is often very rapid. It is recorded of a rock on the coast of Scotland which is uncovered only at the lowest tides, that it was one year chiselled smooth in November, and that on the following May, less than six months afterwards, it was thickly covered with ribbon kelp two feet long, and ordinary kelp six feet long.

Composition of Sea-weeds.

Analyses of various kinds of fuci by Anderson, Forchhammer, Marchand and others show that these weeds contain when fresh 70 to 80% of water, 0.33% of nitrogen, 18 to 24% of organic matter, and 3 or 4 or even 5 or 6% of ashes. In 100 parts of the ashes there are contained 10 or 12 or 15 or even 20% of potash, 2 or 3% of phosphoric acid, 10 or 12% of lime and 6 or 7% of magnesia. It is to be remarked that the percentage of ashes is very high; Marchand has observed that it amounts to from 10 to 20% of the absolutely dry weeds. But in ordinary cordwood there is usually no more than 1 or 2% of ashes.

Sea-manure a Potassic Fertilizer.

It appears from all this, that the sea-manure, though a "complete manure," as the term is, — i. e. one capable of yielding to crops nitrogen, phosphoric acid, lime, and magnesia, as well as potash, — is nevertheless specially rich in potash; and that it might be looked upon as a potassic manure, much in the same way that guano is regarded as an ammoniacal manure.

It will be shown farther on that the potassic manures are specially favorable to the growth of clover; and it is not a little remarkable that there is perhaps hardly another locality in New England where red clover may be seen growing so freely and abundantly as upon the tract of country back of Rye Beach, just now mentioned, which has been manured with sea-weeds ever since the country was first settled. Clover grows there naturally and spontaneously, in the sense that it perpetuates itself and remains in the land year after year, much as June-grass does in other localities.

Shrinkage of Sea-weeds.

The facts that valuable sea-weeds contain nearly 80% of water, and that eight tenths of all that is not water is a soft, easily decomposable form of organic matter, explain the extraordinary amount of shrinkage that is often noted when heaps of sea-manure are left to themselves. Very large heaps have been known to disappear almost entirely in the course of a couple of years, nothing remaining but a little black fibrous matter, which probably represented the external portion of the original heap that had been made dry and crisp by the action of the weather. It is worth remarking that a mixture of bone-meal and sea-manure would make a very complete manure, perfectly competent to replace dung in many situations.

Ashes of Sea-weeds.

Beside using the fresh sea-weeds directly as manure, it has long been customary, in several European localities, to dry and burn large quantities of sea-weed, and to use the ashes for purposes of fertilization. Thus, on the west coast of France, in Normandy and Brittany, the weeds are dried and stacked, and afterward methodically burned to ashes, in pits, in late summer. It is to be remarked that a similar system of burning prevails on the northwest coast of Ireland, and that in Scotland, also, dried sea-weed is burnt in kilns; but in both these countries the ashes are subjected to chemical treatment, in order to obtain from them iodine and salts of potassium and sodium, so that, beside potash salts, the only product available for agriculture is the insoluble coaly residue which is left when the ashes are lixiviated.

On the islands in the English Channel, as on the adjacent French coast, much sea-weed is burnt. The weeds are dried at the tops of the beaches, and are subsequently kept in thatched stacks, near the peasants' houses, on the hearths of which the weed is burned. In each house a constant, slow, smouldering fire is kept up by frequently adding to it some of the dried weed. The charred ashes are said to be sold at about 12 cents the bushel. On the island of Jersey, these ashes are said to be used particularly upon rich land that is to be laid down to wheat and clover. Such land has usually been highly manured for the potatoes, parsnips or carrots, which precede the wheat. It is said that two and a half tons of the ashes to the acre are applied when the wheat is sown in early winter, and that when the wheat has grown to a height of 4 or 5 inches, clover and other grass-seeds are sown upon it. So large a dressing of the ashes would seem to indicate that much charcoal and sand must be admixed with them. Analyses by Golfier-Besseyre, of many samples of French ashes, show that they ordinarily contain as much as 50 %, and often more, of matters insoluble in water. The rough salts dissolved out by water may contain from 11 to 44 % of sulphate of potash, from 12 to 35 % of chloride of potassium, and from 9 to 70 % of common salt. In some specimens, as much as 35 % of sulphate of soda were found, and in others none. From 8 to 15 % of carbonate of soda were found in some instances, and little or none in others. These differences depend, of course, largely on the varying conditions, as to temperature and access of air, to which the weeds must have been subjected during the process of combustion.

The residue, or leached ash from which the soluble salts have been removed by water, is highly valued as a manure in France, and is said to be carried to distances of 30 miles in the vicinity of iodine factories.

Composition of Mosses.

Hoffmann has analyzed a variety of mosses such as are sometimes used as substitutes for straw for bedding animals. He found in the air-dried materials 14 to 18 % of water, 2 to 6 % of ashes, 78 to 84 % of organic matter, and from 1 to 1½ % of nitrogen. The ashes were rich in potash and phosphoric acid. One sample of ash contained as much as 6 % of phosphoric acid, and in two samples there was contained 3 %.

Sawdust and Tan-Bark.

In connection with straw, a few words may be said with regard to sawdust and to spent tan-bark, which often suggest themselves to the farmer as fit materials for the bedding of animals and for the preparation of compost. Speaking in general terms, neither sawdust nor tan-bark can be very strongly commended. They do not contain enough fertilizing matters to make them valuable as manure, and they are distinctly inferior to straw, leaves, sods, and peat as materials for compost, or even for mulching, though there are, of course, some particular instances in which they can be made to serve a good purpose.

Tan-bark is well-adapted for mulching fruit-trees and strawberry-vines in many cases, and when dry it may be used with advantage for bedding animals, — excepting sheep, whose wool would be clogged by it, — but it needs to be kept under cover until the moment of use, in order that it may be dry. At one time it was thought that spent tan-bark which has lain for a long while in heaps and become rotten, was an excellent manure for cold, stiff clays, the more especially because it "loosens and separates the earth. . . . When this manure has been used 3 or 4 times, it has made land very loose which before was strong and not easy to be wrought." (Duhamel.)

Dry sawdust is said to be superexcellent for bedding cows, since it keeps them perfectly clean, and is light and easily shovelled and readily spread in the fields; and a somewhat similar remark will apply to short shavings of wood such as are produced in planing-mills and by the turner's lathe. Experiments are recorded on a subsequent page which show that dry sawdust can absorb some three times its own weight of liquid. But on this very account the material is not much esteemed for bedding horses, since it is supposed to make their hoofs dry and brittle, and since horse-manure charged with much sawdust is particularly liable to spoil in process of fermentation, because the heaps are so light and dry. Even cow-manure admixed with sawdust may firefang, like horse-manure, in the course of a fortnight, if left in a large heap. It is well to haul it out as fast as it is made, and to leave it in small heaps on the fields to which it is to be applied.

It is not improbable that sawdust may sometimes play a more important part in compost-heaps made with cow-manure than was at one time supposed, for practical experience has shown that sawdust serves very well for fermenting bone-meal when the two substances are mixed in equal weights and kept in a moist heap.

The question of the chemical composition of sawdust, tan-bark, and leached dyewoods has been treated of at considerable length in an article in Vol. II, p. 26, of the Bulletin of the Bussey Institution, to which the reader is referred.

Sawdust is poor in organic constituents, though in respect to nitrogen it contains more than straw. Indeed, the best use for sawdust (agriculturally speaking) is for bedding neat cattle, care being taken, of course, to sift out all splinters and lumps, such as knots.

Spent tan is poor in everything, and is practically useless, except as a mulch, or for altering the texture of soil.

The following table of comparisons is from the Bussey Bulletin, Vol. II, p. 50: —

Per Cent of	Saw-dust.	Spent Tan.	Straw.	Eel-grass.	Twigs with Leaves.	Best Autumn Leaves.
Potash	0.10	0.08	0.50 to 1.00	1.02	0.88	0.10 to 0.50
Phosp. Acid . . .	0.05	0.04	0.20 " 0.30	0.23	0.33	0.06 " 0.30
Nitrogen	1.00	0.16	0.33	1.30	1.28 to 2.84	0.75

It will be noticed in this enumeration that the fertilizing value of young twigs is really very high. Cato in his time directed that, "If a vine should happen to be but poor and meagre, prune the shoots of it and plough them in round about it."

CHAPTER XVIII.

HUMUS, OR VEGETABLE MOULD.

The importance of humus as a source of nitrogen is most conspicuous when wild plants are considered. In spite of all that may be said of the importance of Symbiosis, it still remains true that it is from the humus of the soil that most plants, growing naturally, derive the greater part of their nitrogenous food.

Some nitrogen, indeed, comes to all land with the rain and dew that fall upon it. But the amount of this atmospheric nitrogen brought down by rain is comparatively small, and is, by itself, no more than sufficient to nourish a sparse vegetation, or vegetation of a very low order. Some assimilable nitrogen, in the form of nitrates, is found in the waters of brooks also; and the plants which have access to such waters profit by the nitrates that are contained in them, as will be shown under the head of Irrigation. But only comparatively few plants are so situated that they can be nourished by brook-water; and, besides, a good part of the nitrogen in such water is derived, doubtless, from the oxidation of humus, up the stream.

As has been shown, some free nitrogen from the air is oxidized by electrical discharges, and as an incident to combustion, and so made available for feeding plants. Some is fixed in the soil by micro-organisms, living there, which can absorb free nitrogen from the air, and much nitrogen is brought to leguminous crops, and to various other plants, by microscopic parasites which feed upon their roots. But the fact remains, nevertheless, that humus must be looked to as of paramount importance for supplying nitrogen to many kinds of plants.

Humus a Reservoir of Nitrogen.

One of the most important attributes of humus, as found in fields and in swamps, depends upon the fact that it is a reservoir of nitrogen, which has been accumulated upon the land by the generations of plants which have lived and died there. The lichens which appear on the bare rock with the first suggestion of disintegration, take in nitrogen from the air, and convert it into vegetable matter, while the mosses and hardy plants which succeed them all accumulate nitrogen from the waters by which they are nourished, — much as the swamp-mosses accumulate it to be stored in peat; and they yield after death a nitrogenized humus which tends to increase in quantity in temperate climates as long as the land or bog is left under the natural conditions, i. e. covered with vegetation, and neither exposed to fires nor to the denuding action of water. In all such cases, the humus appears to have accumulated in the places where it is found, by virtue of plant-food which has been gradually brought to those particular spots, from other localities, by means of water. This store of humus is capable of supplying nitrogenous food to many successions of crops, when the land comes to be cultivated, and to be subjected to processes of nitrification.

The Character of Humus varies with the Climate.

Humus may assume very different conditions, according to climatic and other circumstances to which it is exposed. But the fact of its accumulation in countries that are neither too hot nor too dry is none the less a general fact. In temperate climates, peat is often formed, while within the tropics peat is said to be unknown, except upon high mountains at an elevation of several thousand feet above the sea-level. In hot climates, the surplus humus occasionally collects in enormous beds of black mould of extraordinary fertility. But in cold, high latitudes, the tendency is to form moorland rather than peat-beds, at least in many situations; and there are thousands of miles covered with a deep black humus, rich in nitrogen, it is true, but cold and sour, and well-nigh unfit for the support of plants. A somewhat similar product occurs in New England as a cold, sour, black earth found at the tops of high hills.

Even in middle and southern Europe, very remarkable contrasts are to be seen, as between the moor-earth of northern Germany, the sour humus of some parts of France, and the famous black earth of central Russia. The Russian black earth is a soil of extraordinary natural fertility, which has long been celebrated for producing continually great crops of wheat and grass. It covers a wide extent of territory, and appears to have been formed by the accumulation of mild humus in and upon beds of fine mud or silt that were originally deposited at the bottom of an ocean, and subsequently upheaved. It has been argued that, as the land slowly emerged from the water, the silt probably remained for a long time in a miry state favorable for the growth of humus-producing plants. This black earth is rich in nitrogen of good quality, and contains ample stores of phosphates and of other forms of plant-food. It is a formation of so much importance that reference is sometimes made to it as if it were a national characteristic. According to the Danish author, Brandes, "The Russians have an expression, *Chernoziom* — the black earth-mould. They mean by it the broad and deep belt of fertile soil, *humus*, which extends from Podolia to Kasan, and even across Ural into Siberia. The wonderful fertility of this soil is ascribed to the slow decay of the grass of the Steppes, which has been going on for centuries. The richest and broadest Russian natures remind one of this belt of rich soil."

Beside differences so radical as the foregoing, a great variety of products is necessarily comprised within the meaning of the term "humus," since the substances which result from the decomposition of organic matters differ from one another materially, according as the decomposition has been slow or rapid, and as it has occurred in heaps or beds, or in the manure-heap, in the soil, or under water. As here used, the term "humus" includes peat and swamp muck and vegetable mould, and the organic portion of all the earth-like products that result from the decay of vegetable or animal matters.

Conditions favorable for forming Humus.

It is to be noticed that the circumstances which favor the formation of humus are somewhat peculiar, as regards access of air and moisture. If the decaying vegetable matter — say the leaves of trees — were but supplied from the first with an excess of air, and kept somewhat moist and warm, it would soon oxidize completely to carbonic acid, water, ammonia, and nitrates, and perhaps free nitrogen. It would be consumed, in fact, as if by fire, so that nothing would be left upon the land but a little ashes. But under the conditions which actually obtain in temperate or cold climates, the leaves, or what not, accumulate in damp beds, thanks to the action of wind or flowing water, or they are buried more or less completely beneath other leaves; so that the supply of oxygen that reaches them is limited, and the process of combustion is checked far short of the final products of which mention was just now made. Every farmer is familiar with the great differences exhibited by humus accordingly as it is cold and sour, when formed in places surcharged with water, to which air can have no easy access, or ripe and mellow, as it occurs in soils which are fairly dry and well aerated. In case the vegetable matter is immersed wholly or in part in water, so much the slower will the oxidation be. But in warm, open air, the reactions are very different. For example, Mr. Smith, in describing the great forests on the Amazon, writes as follows: —

"How are the trees nourished? The ground is sandy, as it is almost everywhere along the Amazons, and not very rich; it is nearly bare above, for mould does not form in the tropics, except about swampy places. At the North, the leaves fall together and rot under the snow; but here they drop one by one, all through the year; they dry up, are broken to dust, and so pass away in the air.

Fallen logs and branches are eaten by insects. There is nothing left to form a rich soil of.

"In fact, it is a mistake to suppose that all this rampant tropical growth depends on any inherent fertility of the ground. The sun and the moist air [and he might have added, the enormously rapid nitrification] make up for barren soil. Beside the rains, there are the heavy dews, and the winds are always soaked with moisture. The sand has no [visible] richness of its own, but it aids growth by carrying rain to the thirsty roots. Water does not collect at the surface; it sinks at once, and is evenly distributed to a great depth, and in this climate the ground has no chance to dry up."

So, too, when land in temperate climates, instead of being left to itself, comes to be cultivated, there will then be in many cases a constant drain upon the humus; and in order to keep up the fertility of the field, there may sometimes be need of applying to it new quantities of nitrogen, either in the form of farmyard-manure, of leguminous crops, of artificial fertilizers, or of peat taken from some place where humus has accumulated in excess. It is recognized nowadays that the farmers are wholly right in attaching great importance to the preservation of humus in their fields, though the old theories by which the practice has been justified are for the most part untenable.

Humus proper resists Decay.

In temperate climates, when vegetable matters are first exposed to decay, most of the available oxygen that happens to be in the vicinity is speedily used up by combining with those portions of the substance which decompose most readily. In other words, the more tender portions of the vegetable matter are converted into carbonic acid and water, — chiefly by the action of micro-organisms, — while a residuum of humus is left. But when once formed, this humus has considerable power to resist further change. There are formed, during the first stages of decay, a number of solid products, of such character that they do not readily suffer further decomposition, or take on more oxygen, so long as they remain soggy and not freely exposed to the air. Hence the accumulation of humus in woodlands, pastures, swamps, and bogs, where vegetable matter is supplied in abundance under conditions that hinder the access of oxygen.

Old Humus specially Resistant.

Humus does, of course, slowly oxidize in the soil when exposed to the air, and, in general, it changes more or less rapidly, according as it is new or old. It should be said, indeed, that the destruction of the tender portions of the original vegetable matter, as just now described, can hardly be regarded as of the nature of a definite step. After the tenderest portions of the plant have wasted away, the less tender will be acted upon in their turn, and so on continually so long as anything is left. It is true only that in the main the decomposing action proceeds more and more slowly in proportion as the humus becomes older. It is a familiar observation that a heap of green weeds will decay rapidly at first, while a heap of peat or loam, subjected to similar conditions, will decay slowly. But when the first hot fermentation of the weeds has run its course, there will be left a quantity of humus, which will decay but slowly. Lawes and Gilbert have determined, in soils taken from several of their experimental wheat-fields, the relation which the carbon in the humus bears to the nitrogen. Thus, on unmanured land, they found 10 of carbon to 1 of nitrogen; on land dressed with farmyard-manure there was nearly 12 of carbon to 1 of nitrogen, and on land fertilized with a mixture of minerals and ammonium salts, the proportion was as 10.5 to 1. But in farmyard manure the relationship between carbon and nitrogen is as 25 to 1. Here, again, is evidence of the fact that the carbon in vegetable remains often goes to waste more rapidly during processes of slow decay than the nitrogen does. So, too, the character of the organic matter in a surface soil is usually distinctly different from that in the subsoil. The uppermost 9 inches of old pasture-soils at Rothamsted, freed from roots, contain 13 of carbon to 1 of nitrogen, while in the clay subsoil taken below 3 feet from the surface the proportion of carbon to nitrogen is as 6 to 1. In soils from Manitoba, taken to a depth of one foot, the relation of carbon to nitrogen was as from 12 to 14 to 1. The experiments of Lawes and Gilbert tend to show that the nitrogenous organic matter in subsoils is not so readily nitrified as that of surface soils.

Waste of Humus by Tillage.

But, while humus may accumulate in forests, pastures, clover-fields, and boggy places where the land is constantly covered with vegetation, it may speedily go to waste when the soil is loosened by tillage. It was observed by Humboldt long ago, then by Schuebler, and latterly by many chemists, that moist humus absorbs oxygen freely from the air, and that the higher the temperature so much the more rapid is the absorption of oxygen. On the other hand, several chemists have experimented as to the rate at which humus wastes away from cultivated fields, and their observations go to show that this waste is sometimes very rapid. Thus Boussingault found that a sample of rich soil from his garden in Alsatia, which had been heavily manured with dung for many years, lost one-third of its carbon when it was exposed to the air, and watered daily, during the three summer months, July, August, and September. At the beginning of the experiment there was 2.43 % of carbon in the soil, and at the close, 1.6 %; the loss was 0.83 %.

Stoeckhardt, also, in a set of experiments, to be described on a subsequent page, which were made for the purpose of determining how much influence can be exerted by humus in decomposing minerals, found that the waste of humus in the soil may be very rapid. His experiments were repeated during several summers, and were as follows: Quantities of rich vegetable mould from a grove of very old beeches were mixed with sandy loam, and planted with ray-grass and maize. It was found that the more humus there was in the loam, the more rapidly did this humus go to waste. It was found, also, that the amount of humus lost could be increased enormously by heating the earth artificially. Thus, in some of the experimental boxes, hot-water pipes were so arranged that the temperature of the earth could be kept constantly some 8° or 10° C. higher than that in the boxes exposed to the ordinary summer air, and it was found that, in the superheated earth, from 18 to 38 % of the original humus was lost; or, in other terms, from 16 to 40 % of the original carbon, and from 18 to 47 % of the original nitrogen.

Voelcker found, in his turn, that the waters which escape through tile-drains, even from unmanured fields, contain appreciable quantities of nitrates, which have been formed through the oxidation of humus, and that more considerable quantities of nitrates are carried away in the waters that drain out from fields which have been dressed with nitrogenous fertilizers.

On comparing the soil of his old pasture with that of his arable land, which is known to have been under cultivation for more than

250 years, Lawes has estimated that some 3,000 lb. of nitrogen per acre must have disappeared from the arable land since it first came under the plough. Some examples of the waste of nitrogen from this land in recent years are given in the following table. Per cent of nitrogen in the first 9 inches of the soil of an —

Old pasture	0.250
Arable field, in ordinary culture	0.140
Wheat-field, unmanured for 38 years	0.105
Wheat and fallow, unmanured for 31 years	0.096
Barley-field, unmanured for 30 years	0.093
Turnips, unmanured for 25 years	0.085

It will be noticed that, where grain was grown continuously without manure, the nitrogen has fallen to a point much lower than is reached in ordinary arable culture, and that the reduction is particularly well marked in the case of the turnips. Other experiments showed that the decrease of the soil-nitrogen was rapid when arable land, which had been brought into high condition by heavy dressings of manure, was afterwards cropped continuously without any further application of manure.

It is now recognized that the waste of humus is due chiefly to the activity of microscopic organisms living in the soil, and that the conditions favorable for their development are aeration of the soil, as by tillage and drainage, warmth, an adequate supply of moisture, and the presence of a certain proportion of carbonate of lime. In a sour, water-logged soil, on the contrary, the tendency will be for humus to increase rather than to diminish.

Raking of Woodland.

The foregoing results of Stoeckhardt led to another series of experiments, since they bore forcibly upon a question which has excited much ill-feeling in Germany, viz., whether woodland should ever be trimmed, or the farmers and peasants ever be permitted to rake up and carry away the leaves and other refuse which fall from the trees.

Time out mind, the foresters whose duty it is to promote the growth of merchantable wood have set their faces against such trimming and raking, and in most of the European states very stringent laws are enforced to prevent such "robbery," as it is termed.

But, on the other hand, it has seemed to almost everybody except the foresters to be rather hard that the seemingly worthless leaves and dead branches should not be put to immediate use, either for bedding cattle or for baking bread. Sir Francis Head has dwelt very forcibly upon the essential meanness of the German wood-laws, in his somewhat famous little book, "Bubbles from the Brunnen of Nassau."

It is probable that, in most instances, the harm done by raking woodland depends more nearly upon the removal of the mulch which the litter affords, than upon the loss of the fertilizing constituents in the litter; that is to say, the removal of the mulch deprives the trees of water. This view of the subject has already been suggested under the head of Mulching, and it may be still further illustrated by the following figures, which represent the averages of many Bavarian experiments, as reported by Ebermayer. Through drain-gauges having an area of 1 square foot at the surface, that were kept in the woods, there percolated, at a depth of —

1 foot when no litter was on the soil . . .	253	cubic inches,
1 foot when litter was on the soil	475	"
2 feet " " "	514	"
4 " " " "	257	"

more of water than percolated through similar gauges not covered with litter that were kept in open fields. In sum, the three mulched gauges kept in the woods delivered 1,246 cubic inches more water than the three corresponding gauges in the fields.

Nevertheless, the fertilizing matters in the litter of woodland are of no small importance, as will appear from the following statements of experiments which were made by Stoeckhardt upon the soils of several parcels of woodland to illustrate whatever of truth there might be in the foresters' view of the subject. Localities were sought out where contiguous patches of forest had been raked and protected, and the soils of each patch were analyzed, with the following results: —

A sandy soil covered with pines 50 years old was first examined. One patch of the woodland belonged to the Saxon government, and had been protected from depredations for many years, while the adjacent patch had been subjected to periodical rakings until very recently.

The results as given in the table relate to half-acres of land, and to soils taken to the depth of twenty inches. The amounts of the several ash-ingredients enumerated are the quantities which were found to be soluble in water, given in pounds.

	Potash.	Lime.	Magnesia.	Phosp. Acid.	Organic Matter.	Nitrogen.
On surface of the protected patch (25,600 lb. of matter) . . .	58	92	64	94	8,580	123
On the unprotected patch (5,000 lb. of matter)	4	28	14	17	865	14
In the upper soil: —						
Protected	400	224	80	336	22,240	1,032
Unprotected	272	256	82	280	8,080	528
In the lower soil: —						
Protected	2,240	1,760	480	2,240	38,000	3,060
Unprotected	1,600	640	120	2,080	20,800	1,800

Further experiments showed that, while the protected soil contained 12 % of fine soil capable of being held in suspension by water, the other had only 6 %. And while the protected earth could hold 43 % of moisture, the other could only hold 33 %.

A similar set of experiments made with loamy soil from another forest gave the results recorded in the following table. The amounts of potash, lime, magnesia, and phosphoric acid are those soluble in water, given in pounds: —

On the surface: —	Potash.	Lime.	Magnesia.	Phosp. Acid.	Organic Matter.	Nitrogen.
I. Protected for 40 years (22,500 lb. thick moss)	95	150	49	130	14,000	187
II. Protected 30 years (27,000 lb. needles)	86	116	53	105	16,500	244
Unprotected (18,000 lb. moss and heath) . .	37	160	43	71	5,700	74
In upper soil: —						
Of I	1,220	540	180	1,330	83,200	6,900
Of II	1,340	620	225	1,730	91,200	7,600
Unprotected	1,150	500	145	1,270	79,200	5,600
In lower soil: —						
Of I	4,400	2,600	1,000	5,600	160,000	11,700
Of II	5,100	3,300	1,160	6,600	168,000	12,800
Unprotected	3,700	2,400	1,050	5,600	172,000	12,400

Naturally enough the differences between the protected and the unprotected soils are less here in the case of loam than in that of the sandy soil. The absorptive power of the loam for potash and nitrogen is noticeable. These experiments are fully in accord with the experience of farmers who have to do with light sandy soils. One great difficulty in dealing with such soils is, that the organic matter of barnyard manure is rapidly consumed in them by oxidation during hot summer weather. The epithet "hungry" is appropriately applied to open, porous soils, where the conditions are favorable for the oxidation of humus.

Stoeckhardt dwells on the care that should be exercised in order to protect the humus in a soil when wood is cut off it; but there is small use of talking of that matter here in America, this land of forest fires.

It is a point to be remembered, however, that the destruction of humus by oxidation or fermentation is always very much slower than that of the vegetable substances from which it has been formed would be under equally favorable conditions. It is a matter of experience that peat decays in the soils of cultivated fields more slowly and regularly than the organic matter of stable-manure, or than that obtained by ploughing under sod or stubble. Hence, no doubt, one reason why peat composts often answer so good a purpose when applied to sandy soils.

It needs to be said yet again, perhaps, that the processes of decay and putrefaction which vegetable matters undergo in the soil are in no sense processes of unmixed oxidation. It has been for the sake of the argument merely that they have been alluded to as if they were such. These processes are not even purely chemical, for it is known that microscopic organisms of various kinds usually take part in them. Nothing can be more certain than the fact that micro-organisms play an important part in bringing about the decompositions of organic matters in the soil, and in the elaboration of plant-food also. The formation of moor-earth in cold countries, for example, and that of leaf-mould in warmer lands probably depends on the absence or presence of definite species of microscopic organisms which can or cannot live and prosper in cold or hot climates.

Nevertheless, it was a simple and convenient idea to suppose that humus is formed by processes of incomplete combustion, much in the same way that charcoal is formed by the incomplete combustion of wood in the earth-covered mounds of the charcoal-burner. Just as black charcoal, or red charcoal, or merely charred wood, may be got by admitting more or less air to the heap, so there may result different grades of humus, according to the amount of air.

It may be argued further, that, since the carbon and the nitrogen of vegetable matters oxidize less rapidly than the hydrogen which is contained in them, humus must necessarily contain a larger proportion of carbon and of nitrogen than the materials from which it has been formed. It is known that, beside carbonic acid, there is given off from the decomposing matters some marsh gas, CH_4, and probably a little carbonic oxide, as well as ammonia, sometimes free nitrogen, and not infrequently sulphuretted hydrogen.

Sulphides in the Earth of Marshes and Moors.

Several investigators have called attention to the fact that moor-earth, when out of contact with the air, is apt to contain sulphides, sulphuretted hydrogen, and free sulphur that have been formed through reduction of gypsum or some other sulphate. So, too, on digging deeply into the soil of a salt-marsh which is in process of reclamation, the odor of sulphuretted hydrogen is very evident. It has been noticed in several instances that microscopic algæ take part in this reduction of sulphates. Not only is sulphuretted hydrogen gas set free by the action of the algæ, but solid sulphur also. Particles of sulphur have been found in abundance in the cells of these plants, and it has been shown that the process of reduction may readily be checked by applying chloroform or carbonic acid to hinder their activity. As Cohn has suggested, this reduction of sulphates by algæ is perhaps nothing more than a particular instance of what occurs in all kinds of plants. Sulphates are in fact reduced in the cells of all plants, but the sulphur usually goes to form a constituent part of the albuminoid matter of which the plants are in some part composed. In the case of the algæ, it happens that the process of reduction is specially active and that more sulphur is set free than is needed by the albuminous matters which these plants contain.

Since the sulphides above mentioned are injurious to vegetation, it is clearly desirable to prevent their formation by cultivating the earth in such wise that air may be freely admitted to it. It is to be remembered, however, when moor-land is to be reclaimed, that the first processes of draining and cultivating, by the very fact that they admit air, may lead to the formation of sulphate of iron through oxidation of sulphides already in the soil. Hence the importance in some cases of thoroughly liming moor-land as soon as it has been laid dry.

In some sterile soils examined by Voelcker, the color, which was almost black, was due not so much to organic matter as to the presence of finely divided ferrous sulphide, a substance most obnoxious to the growth of crops. When acted upon in moist air by carbonic acid from the air or from the soil, this ferrous sulphide gives off sulphuretted hydrogen, which is known to be injurious both to vegetable and to animal life, and which in Voelcker's opinion may do even more harm to crops than copperas.

Pagel has suggested that the bad effects attributed to stagnant water are likely enough due in some part to the formation of sulphides in the places where it stands. It is noteworthy that Pagel found that considerable quantities of ammonia were given off from the moor-earth simultaneously with the formation of sulphides, when the conditions were favorable for reduction of sulphates.

By oxidation of the sulphides in moor-earth, free sulphuric acid, or more often soluble ferrous sulphate, are liable to be formed, and the presence of either of these substances makes the soil infertile. To remove or destroy the poisonous ferrous salt, draining, liming or marling, and thorough aeration of the soil are recommended. When the bottom of the Harlem Sea in Holland, was first laid dry, some strips of soil were found to be so highly charged with sulphides that they had to be limed before crops could be grown upon them.

Voelcker and Maercker agree that the mere presence of ferrous oxide, even in considerable quantity, does not necessarily render moor-earth uncultivable, so long as the iron remains in insoluble combinations, such as a double ferrous and calcic humate, for example. Indeed, it is to be presumed that reclaimed marsh-lands, and many other soils rich in humus, such as are renowned for their fertility, must usually contain more or less of the ferrous oxide in combination with humates or silicates. But it is none the less true that many unproductive soils contain considerable quantities of ferrous oxide, and hardly any red ferric oxide, and upon uplands this condition of things is regarded as a sure sign of poor cultivation. Such soils may usually be greatly improved by draining and subsoiling, or by other mechanical operations which tend to admit air. (Voelcker.) The presence of large quantities of ferrous oxide always goes to show that the soil is not sufficiently aerated for the support of the healthiest and most nutritious herbage.

Chemical Substances obtainable from Humus.

Little is known as yet as to the precise chemical composition of humus. Much time and labor were expended by the earlier agricultural chemists in studying peat and vegetable mould, and they did, in fact, extract from these substances several tolerably well-defined compounds, such as humic acid, humin, ulmic (or geic) acid, ulmin, crenic and apocrenic acids, etc. But next to nothing is known as to the significance of any one of these things in so far as concerns the growth of plants.

It is in brown humus, which is an early product of vegetable decomposition, that ulmic acid and ulmin are found; while the black humus, into which brown humus is converted by decay, contains humic acid and humin.

Humic acid and humin may be obtained artificially by boiling sugar, starch or gum with alkalies, or with strong muriatic or sulphuric acids. So, too, by gently heating sugar with dilute muriatic acid, a dark-colored insoluble acid is obtained, which is thought to be identical with ulmic acid.

A mixture of impure humic and ulmic acids may readily be prepared by stirring some peat or garden-loam into a solution of saleratus, straining off the dark-colored liquor through a cloth, and neutralizing it with an acid. The impure humic acids will separate in the form of light flocks.

It is noteworthy that the investigators who have operated in this way with the utmost care have seldom or never been able to obtain products free from nitrogen. One of Mulder's samples contained 1.8 % of nitrogen and Jongbloed found 0.81 %. Detmer in his turn detected as much as 1.5 % of nitrogen in humic acid obtained by precipitating a solution of humate of ammonia by means of mineral acids. Even after boiling with potash lye, reprecipitating with an acid, and repeatedly dissolving with saleratus and precipitating again with acids, the humic acid obtained still contained 0.79 % of nitrogen. Sostegni found even 2 to 2.2 % of nitrogen in humic acid prepared from peat. These results are interesting as indicating the probability that the humic acids of peat are often combined with nitrogenous basic compounds, such as have been discovered by Loges, and that they can retain a part of these basic bodies with considerable power. The composition of humic acid prepared from sugar has been said to be $C_{40}H_{24}O_{12} + 3\,H_2O$, and that of ulmic acid $C_{40}H_{28}O_{12} + H_2O$.

Crenic and apocrenic acids are products of the further oxidation of humus. Salts of crenic acid are found especially in moist soils, where the circumstances favor reduction, and those of apocrenic acid in loose dry earth, where oxidation is not only possible, but easy. It is not difficult to convert either one of these two acids into the other artificially, by processes of oxidation and reduction. In order to exhibit these changes, some chemists have written the formula of crenic acid $C_{24}H_{24}O_{16} + 3 H_2O$, and that of apocrenic acid $C_{24}H_{12}O_{12} + H_2O$, although there is small probability that either of the formulas is correct. Indeed, it is said that both crenic and apocrenic acids really contain nitrogen. Both of these acids are soluble in water, and their compounds occur, in small proportion it is true, in all fertile soils. They probably have no inconsiderable influence upon the growth of plants, although nothing is known as to the manner of their action.

The Humic Acids have considerable Chemical Power.

The humic acids, as they are often called collectively, exhibit considerable chemical activity, in spite of the fact that they are very sparingly soluble in water. Eichhorn has shown that mixtures of humic and ulmic acids, and sour peat also, can decompose dilute solutions of the chlorides of potassium, sodium, and ammonium, and of other neutral salts, and set free a little of the hydrochloric or other acid which the salt contained; so that sour earth, to which a neutral salt has been added, may, after a while, give a sharper and seemingly a stronger reaction for acidity to test-papers or even to the taste than the earth could have given by itself. No such acidification occurs, however, when the peat or other earth examined contains no free humic acid, but only humates. It has been noticed in Germany, on applying potash salts to certain kinds of moor-land, that harm may be done by sulphuric and muriatic acids which are set free in the soil in small quantities through the action of humic acids on the fertilizers.

Reactions analogous to those with the chlorides occur when bone phosphate of lime or precipitated phosphates are mixed with free humic acids, though the decomposition of the phosphate never goes very far. The reaction is promoted by the presence of neutral sulphates, such as those of the alkali metals. Naturally enough, all these reactions are hindered by the presence of substances such as marl, lime, and manure, which work to neutralize free humic acid. It is to be inferred from the foregoing that sour peat, admixed with bone-ash or bone-black, and kept moist, will slowly combine with these materials to the neutralization of its own acidity and the improvement of the phosphate. Hence the propriety of using insoluble phosphates on bog-lands which are undergoing reclamation.

This idea has occasionally been put in practice on the reclaimed gravelled meadows of North Germany. Guerin reported, in 1858, an instance where, by the application of bone-black alone, rye was grown with great success, for seven consecutive years, on land so sour that it had been regarded as unproductive before the application of the phosphate. Peruvian guano, of equal money value with the bone-black, applied for the sake of comparison to another parcel of the land, failed to bring a crop of rye, since the plants all ran to leaf. It seems probable, in this instance, that, beside the direct chemical action of some of the constituents of the bone-black to neutralize the acidity of the soil, fermentations may have been induced by the presence of the phosphate, whose products would serve in their turn to improve the condition of the land, as well as to promote the growth of the crop. It should be clearly understood, however, that the reaction between free humic acids and insoluble phosphates is but feeble, and especially as regards phosphate rock, even when this material is finely powdered.

It need hardly be said that the presence in a soil of any considerable quantity of free humic acids must be prejudicial to the growth of crops. As practical men well know, sour humus needs to be ameliorated by draining and cultivation, by additions of gravel and manure, and by neutralization with lime or marl or phosphatic slag, before useful plants can be grown upon it.

Humic Acids may Expel Silica.

It was noticed by Liebig that silica is less readily absorbed by soils from a solution of water-glass in proportion as the soil contained more humus, manifestly because the humic acids held firmly to the bases with which it was combined; and Vogel has insisted that plants growing in soils rich in silica but poor in humus generally take up much less silica than plants growing in soils rich in humus even though poor in silica. He holds that good loam is usually well fitted for supplying silica to plants, the inference being that the humic acids of the organic matter act upon silicates in the soil slowly to decompose them and supply to the plant-roots some form of soluble silica. Vogel claims that the presence of much silica in sedges and the other inferior herbage of swamps depends upon the abundance of humus in such situations. The suggestion is an interesting one, as pointing to the probable action of humic acids on many inert combinations in the soil to set free from them inorganic foods of one kind or another for the use of crops. Compare Grandeau's observations on a subsequent page, concerning the presence in loams of soluble compounds of ash-ingredients and organic matter.

Considered as a reservoir of acids, humus is doubtless stronger than soluble silica, in the sense that it can combine with bases so firmly as to hold them against this competitor. It has been noticed that, other things being equal, soils can "fix" more silica that is added to them in the soluble state in proportion as they contain less humus; and that, conversely, less of the silica is precipitated and retained by a soil in proportion as it is richer in humus.

Beside the compounds above enumerated, humus contains the obscure nitrogenized matters which have been so often referred to, and no one knows how many other things beside.

Humus may do Good in several Ways.

It is to be observed that the value of humus as a manure depends upon a variety of properties. In the first line, no doubt, must be placed its power of supplying nitrogen to the plant.

Then, by virtue of its porosity, it imbibes and absorbs and holds water, and the vapor of water. By its lightness, too, it improves the texture of many soils, and it may absorb and hold ammonia and the salts of ammonia, as well as various other substances.

It promotes chemical action in the soil, both by means of the acids contained in it, and by those of the character of crenic and apocrenic acids which are formed by its decay. Moreover, by its slow decay, humus supplies carbonic acid for the dissolving of plant-food, as has been explained before.

Some of the materials rich in humus, such as marsh-mud, harbor-mud, and pond-mud, may even be valuable occasionally because of the inorganic constituents which are contained in them.

The power of humus to bring about disintegration and solution of mineral matters in the soil doubtless depends upon a variety of circumstances. But it is very evident that it must be of great importance in the economy of nature. Many facts might be cited in illustration of this point. For example, Peters found that, while the addition of humus to a soil containing ferric phosphate had no immediate effect in increasing the amount of phosphoric acid that could be washed out with water, it nevertheless increased the solubility of the phosphate materially when left in the soil long enough to undergo decomposition, and so reduce a portion of the ferric phosphate to the state of a ferrous salt. The experiments of Stoeckhardt, also, already referred to when speaking of the waste of humus in cultivated fields, clearly exhibit the solvent action of humus. A number of boxes were filled with sandy loam; the loam in some of the boxes was mixed in various proportions with humus from a grove of old beech-trees, and upon the soils thus prepared ray-grass and maize were cultivated. In some of the boxes hot-water pipes were placed, so that the temperature of the earth could be kept continually 8° or 10° C. higher than that exposed to the ordinary summer air.

It appeared that the following quantities of materials had been made soluble in the course of the three summer months, by chemical action in 25,000 grm. of earth: —

Grams of	Earth rich in Humus.		Earth poor in Humus.	
	Ordinary Temp.	Heated.	Ordinary Temp.	Heated.
Lime	7.78	7.23	11.57	13.63
Magnesia	3.30	2.44	0.00	1.97
Potash	5.88	8.60	5.11	1.42
Phosphoric acid	3.11	6.02	3.36	1.64

Humus often improves Tilth.

Humus has undoubted value for lightening and mellowing heavy clays, and conversely for binding sands. It may act in the first instance to lighten a heavy soil in the same way that any coarse manure, such as straw or partially rotted chips, sawdust, or tanbark would act, as will be urged when composts are treated of. Something analogous to the granulation thus produced is to be seen in the mealy snow which accumulates in city streets, where many horses and vehicles are passing. Here the presence of a small amount of "dirt" "breaks the grain" of the snow, as it were, sunders its particles, hinders them from cohering, and prevents the snow from becoming firmly compacted into a solid frozen mass.

But there is another finer, more intimate and enduring action which humus shares with clay, that is of far greater importance for the permanent fertility of the land. As has been shown under the head of Tillage, it is necessary, in order that a soil may be fertile, that its particles shall be granular enough to permit air and rain to circulate freely among them. This needful coherence or granulation of the particles of loam is assured by the presence in fit proportion of humus (or clay), which — while itself protected from being puddled by the presence of lime and other saline matters which are dissolved in the soil-water — acts to cement or bind together the fine rock particles or sand which is the other constituent of the loam. This subject has been studied by Schloesing, as follows: —

First, he prepared mixtures of pure sand and pure moist clay, that contained respectively 1, 5, 10, 15, and 20 % of clay, and he left them in the air until they were dry enough to crumble between the fingers.

Upright tubes, at the bottoms of which had been placed bits of glass covered with coarse sand, were filled with the crumbled mixtures, and a layer of cotton was placed on top of each of these columns of earth. Water that contained 2 or 3 ten-thousandths of a lime-salt was then made to fall very slowly upon the cotton, drop by drop, or rather in the form of fine spray, during 3 or 4 days. Under this treatment those mixtures of sand and clay which contained less than 10 % of the clay did not retain their original appearance or their looseness; while the mixtures that contained 15 % of clay remained practically unaltered. New mixtures were then prepared that contained respectively 10, 11, 12, 13, 14, and 15 % of clay, and treated as before, with the result that 11 % of clay from Vannes was competent to hold the sand in granules against the action of the water.

When chalk was substituted for the siliceous sand, rather more of the clay than 11 % had to be used to hold it together; and, in general, more of some kinds of clay than of others was needed for binding sands. The power of the clays seemed to stand in direct proportion to their plasticity.

It appeared, furthermore, that natural loams which contained no more than 5 to 10 % of clay retained their porosity when subjected to the action of the water in the above-mentioned tubes, whence it was plain that such soils must contain some other binding material beside the clay. That this other material is humus appeared from the following experiment.

Some loam was leached with dilute hydrochloric acid, to remove lime and the other bases which had been held in combination by humic acid, according to the ordinary mode of union of acids and bases, and the undissolved portion of the loam was then treated drop by drop with alkaline water to dissolve the humus. So long as the acid was present, no change in the appearance of the loam occurred; but the moment the humus began to be dissolved by the alkali the coherence of the loam was destroyed, and all of its constituents (of which the humus formed but a small portion) fell down to an impenetrable layer of mud.

It was noticed that the destruction of the granular condition of the loam kept pace with the solution of the humus by the alkali; whence the inference that the compounds of humus are colloids competent to act as a kind of glue to cement the particles of earth together. This observation consists withal with the popular belief that humus serves to bind light soils, and to make them firmer.

To test the matter still further, Schloesing prepared humates of lime, iron, and alumina, and made mixtures of them when moist with sand and lime. The following mixtures, from which clay was wholly excluded, were treated with water in tubes as above described: —

	Per cent.	Per cent.	Per cent.	Per cent.
Sand	99	82½	66	0
Lime	0	16½	33	99
Humate of lime	1	1	1	1

All of these mixtures withstood the action of water, even that of distilled water; whence it appeared that a single part of humate of lime was as effective as eleven parts of the Vannes clay to cement the sandy particles.

When these mixtures that contained the humate were moulded into little balls and cylinders, and allowed to dry, they became so hard that they could be thrown upon the floor without breaking, though it was found in general that, when but a small proportion of a humate is admixed with much sand, as in the first column of the figures, the cementing power is somewhat impaired by drying.

Humus may Lighten Clay.

Other mixtures of sand and lime that contained 4 or 5 % of clay together with 1 % of humate of lime or humate of alumina likewise resisted the action of water, the general conclusion being that the humates are better able than clay to bind together particles of sand. It was noticed nevertheless when the two kinds of cementing agents were mixed, that the binding effect was not equal to the sum of the effects produced when the two materials were employed separately. On the contrary the cohesion of clay was lessened by mixing with it a sufficient quantity of the humate.

This fact, which consists with the popular opinion that humus lightens heavy soils, has been illustrated by the following experiments of Schloesing. He kneaded pure clay with water, together with additions of humus compounds, into mixtures that contained respectively 2, 4, and 6 % of the humate, and found that all of them, as well as pure clay, became very hard on drying, one lump being apparently as hard as another. But on bringing the lumps into contact with water they behaved very differently. All of them fell down to the condition of mud, but when the muds were left untouched until dry, the resulting powders were found to be less coherent in proportion as they contained more humus. By direct experiment, it was found that many good soils contain enough humus to bring about the effect just described.

When clay coagulates or flocculates, it can enclose considerable quantities of humus. But more of the coagulating agent (see under Lime) has to be used to coagulate clay that is suspended in an alkaline solution of humus in proportion as the amount of humus contained in such solution is larger. Thus, while from $\frac{1}{1000}$ to $\frac{3}{1000}$ of potassium chloride will coagulate pure clay that is suspended in water, as much as from $\frac{10}{1000}$ to $\frac{20}{1000}$ would be required, if together with the clay 100 to 200 milligrams of humic acid were contained in a litre of water.

Mention has been made already of the action of carbonic acid, derived from decaying humus, to flocculate clay and so improve the permeability of the soil. From all of which it appears that humus may be useful in several different ways. Practically, peat has sometimes been found to do good service on drained clay soils, and a part of the utility may justly be referred to its power of lightening the clay. It has been noticed that peat-waters strongly colored with organic matter sometimes become clear on passing over beds or through banks of clay, though it has been suggested that clays which are slightly acid (from the presence of sulphate of alumina) are specially effective.

Walz has described the case of a small sloping field, in which a thin, well defined layer of stiff clay reposed upon loose, sharp, coarse sand, where frequent ploughing and harrowing failed to commingle the sand and the clay to the condition of loam of medium character. It is to be presumed that a permanent mixture could soon have been made if there had been an abundance of humus in the soil.

Humus retains Moisture.

The power of humus to retain capillary water has already been insisted upon. It is on this account also that humus is so important in sandy soils. Indeed, there are few soils that can dispense with this peculiarity of humus, excepting those which are irrigated or in which the depth of the ground-water is constant and perfect. Here in New England, upon the drift-gravel, manures rich in humus will always be preferred to the so-called chemical fertilizers on this account. The estimation in which peat is held by practical farmers, both as a manure by itself and as a "body" for composts, illustrates this point, perhaps, more forcibly than anything which can be urged from the scientific point of view.

It is sufficient to look in dry summer weather at a gravelly field manured with peat-compost, and contrast the vigorous vegetation upon it with the dried-up crops of the neighboring fields, to be convinced of the power of humus to "draw water." Such fields suggest the thought that there may be such a thing as mulching below the surface as well as upon the surface, and they well illustrate the significance of the hygroscopic power of peat in the sense of Hilgard's observations.

Henry Stewart tells of a case in his experience where 100 loads of swamp muck, well composted with quicklime, having been spread on an acre of very light, sandy soil, saved a crop of maize from injury during a very dry season. The plants dressed with the compost remained dark green in color, and their leaves never curled even on the hottest days; while adjoining rows of corn not so treated became dry and yellow, their leaves curled up and wilted, and there was obtained finally no more than half a crop of ears and stover. In former years the agricultural newspapers were accustomed to bear frequent witness to the great value of peat, and the manures of which it forms a component part. Some sanguine observers have even gone so far as to allege that the best kinds of peat are worth as much, load for load, as barnyard-manure. Professor S. W. Johnson has collected a considerable amount of this kind of evidence, and published it in his excellent little manual on "Peat and its Uses."

It is true, no doubt, that some kinds of bog-earths in limestone regions are really manures which may be applied to the land at once. They may afford excellent crops, even when used in the absolutely fresh condition, without any preparation whatsoever; but with the exception, perhaps, of some regions rich in limestone, such super-excellent humus is by no means common. In non-calcareous districts the peats are, generally speaking, not easily putrescible, and they need to be weathered and seasoned, or even fermented, before they can be used profitably as manure.

Crude Peat is "Sour."

It is a matter of popular belief, here in New England, that the application of raw peat to a cultivated soil would be apt to do actual harm, because of an "acidity" which most of our peats exhibit when first taken from the bogs. It is believed also that this acidity may be corrected, not only by the addition of alkaline matters, such as wood-ashes, marl, or lime, but by mere age and by exposure to the air. Angus Smith insisted, some years since, that "Our great struggle with the soil is to produce alkalinity, or at least to diminish acidity, and where most acids exist we use most lime." And the remark comes with special force from the mouth of a Scotchman born.

Smith noticed the intimate connection between alkalinity and the useful fermentations which occur in soils, and he showed that even putrescence may readily be brought about by adding alkalies to loams. As long ago as 1847, he published an account of observations made "in an alkaline, peaty district where cold weather produced acidity in a few days." "It would appear," he says, "as if the acids of the mould were incapable of further decomposition in the cold, and were thus retained and increased. In a rich, highly-manured soil kept warm, the soil will be found alkaline; though soils generally are [slightly] acid." There are now known many good reasons for believing that the alkalinity in these cases was due to the activity of certain micro-organisms which prosper in warm weather and are inactive when the land is cold.

It is a matter of common observation in New England, that some kinds of bog-mud, when thrown out in great heaps, as when a large ditch is dug in a low-lying meadow, or the course of a swamp-brook is straightened, may lie inert, and "cold" and "sour" for years — as witnessed by the fact that nothing but a sparse vegetation of starveling weeds will be found growing upon the heaps — although this very peat may become a highly fertile soil when "cured."

It is true in general that most peats when freshly dug possess a certain antiseptic or germicide quality which would be apt to hinder nitrification as well as the other forms of fermentation and decay. It was observed long ago in Ireland that sheep never "rot" on a drained bog, and that they can safely be kept on such land. (A. Young.)

Not infrequently mud taken from swamps and bogs, sometimes even pond-mud (Link), contains iron pyrites (FeS_2), which oxidizes readily on being exposed to the air, and forms the soluble salt called copperas or sulphate of iron ($FeSO_4$), as has been said already. Peats which have become thus charged with sulphate of iron are poisonous to agricultural plants, and to the microscopic "ferments" as well; they are most conspicuously "sour." So too, in North Germany, it is not uncommon to find moor-earths which exhibit an intense acid reaction because they contain free sulphuric acid. It appears that sulphur is first set free in the soil either through the reduction of sulphates or of the albuminous remains of plants, and that when air gains access to this sulphur it is slowly oxidized with formation of sulphuric acid. After a while, when all the inorganic matters with which this acid could combine have been washed out from the land, the earth remains charged with more or less free sulphuric acid, which is destructive of vegetable life.

It does not appear, however, that the presence of free humic acids in a soil is always and necessarily hurtful to vegetation. Fairly good crops of rye, buckwheat, potatoes, oats, etc., are grown on many German moors (Hoch-moor) which exhibit a strong acid reaction, both as regards the surface soil and the subsoil. It is none the less true, however, that as a general rule good soils are not strongly acid. Some soils are neutral to test-papers; and, as has just been said, there are some which are faintly alkaline.

But even if the crude peat were to do no damage, it is none the less a fact of common experience that many kinds of raw peat do little or no good to land. Experiments have been made by Greig in Scotland, to test the effect of artificial fertilizers on a bed of peat which had been thrown out from a railway cutting. A number of plots were sown with oats and various clover and grass seeds; but, no matter what fertilizers had been used, every kind of seed failed totally on every plot that had not been dressed with lime; and even where lime had been applied all the crops failed unless phosphates had been applied also. The best results were obtained on plots where, in addition to phosphates of one or another variety, the land had been dressed with 120 bushels of lime, 4 cwt. of kainit and 1 cwt. of ammonia to the acre. In a case like this the use of phosphatic slag could hardly fail to do good.

The significance of lime as a means of improving peat is exhibited very emphatically in France, where a rich, mellow, fertile humus prevails in those districts where the soil and the waters are calcareous, while in the regions of granitic sands sour, infertile moor-earth covers wide tracts of country.

It may freely be accepted, as a general rule, that crude peat is vastly inferior to that which has been mellowed by exposure to the air. Most kinds of peat only show their best power after they have been "seasoned," or, what amounts to the same thing, after they have lain upon the field until the second year from the time of their application. This behavior depends, doubtless, upon chemical changes to which the nitrogen-compounds in the peat and the antiseptic matters are subjected when the peat is exposed to the air. And upon physical changes also which are brought about by the decay of a part of the organic matter. Much importance is to be attached in any event to alterations of texture induced by the expansion of ice when, in the winter, the water within the peat is subjected to alternate freezings and thawings. There is a peculiar gummy, sticky quality in crude peat-mud which is highly objectionable, for when such unregenerate peat-mud dries it takes the form of hard, hornlike clods or gravel, which is antagonistic and alien to mellowness and good tilth. But on leaving the raw peat to lie over winter in heaps its mechanical condition will be so much improved that it can subsequently be changed with comparative ease to the condition of mellow earth. Even though there might be no great harm in applying peat to the land as soon after digging it from the bog as was convenient, there would, generally speaking, be no sense in thus applying it, because no useful effect would be got for a whole year, in the majority of cases. It is possible, moreover, that the useless peat might do harm by interfering with the action of other fertilizers. For it might combine with these fertilizers to form insoluble double humates at a time when they had better not be formed, and it might check the action of the nitric ferment.

It is not known as yet precisely what chemical changes may occur in heaps of crude peat that have been left exposed to the weather, though it is to be inferred from Smith's observations that some products of the decay of the peat are competent to neutralize the free humic acids, and thus to change the crude peat to the condition of mild and mellow humus. As bearing upon this point, the basic substances detected in humus by Loges — as mentioned on page 65 — may have no little significance. Whatever their influence may be, it is known already that when organic matters decay several substances of basic character are apt to be formed, such as ammonia and ethylamin, which are fully competent to neutralize acids; as well as other amids of less pronounced chemical power, such as leucin and tyrosin. There appears indeed to be a certain analogy between the results of the decay of organic matter and the products of its destructive distillation by heat. Thus when wood, or coal, or bone, or almost any other organic compound is distilled — as happens in the processes of making tar, coke, charcoal, bone-black, and illuminating gas — there are found in the distillates a great variety of alkaloids, notably ammonia, and the amines of methyl, ethyl, amyl, phenyl, etc., as well as picolin, pyridin, collidin, parvolin, etc., etc.

As was just now said, the neutralization of the free humic acids may readily be effected artificially by adding to the crude peat lime or wood-ashes, or some other kind of alkali; and the process of decay may be hastened by mixing the peat with dung, or urine, fish, flesh, or blood, as actually happens in the making of composts. Indeed, the best way of using peat is in the form of compost, as will be explained in a special chapter.

Mild Humus as a Solvent.

In addition to the mechanical and chemical effects already alluded to, there is no doubt that some of the better kinds of humus may have considerable influence by directly promoting the solution of plant-food. Gasparin and others have urged that many mineral matters dissolve more readily in the products of the fermentation of humus and other kinds of organic matter than they do in mere water.

Verdeil insisted strongly upon this point many years ago. He observed that fertile soils contain a peculiar, neutral organic substance which is soluble in water and which enables water to dissolve many inorganic matters that are naturally insoluble in water by itself. He found that the solutions obtained on extracting many different kinds of soils with pure water contained this peculiar organic substance combined in such an intimate way with phosphoric acid, lime, magnesia, oxide of iron and silica, that these substances gave no reactions with the reagents ordinarily employed for detecting them in simple aqueous solutions. Speaking after the manner of chemists, he said that the organic matter masked the inorganic matters.

Grandeau, in his turn, has insisted that there is contained in Russian black earth and other rich loams of high fertility, i. e. in garden-loams, in farmyard-manure, and notably in barnyard-liquor, a peculiar organic substance capable of holding combined the inorganic matters above enumerated, in such manner that they resist the action of dilute hydrochloric acid, and cannot be detected directly by means of the reagents ordinarily employed in laboratories.

To obtain this peculiar substance Grandeau directs that loam should be leached with a dilute acid to remove the bases with which the organic matter is naturally combined in the soil; that the excess of acid should be removed by washing the leached loam with water, and that the residue should be treated with moderately diluted ammonia-water, or, for that matter, with either of the other alkaline hydrates. The black matter dissolves readily in the ammonia-water, and in this solution will be contained phosphoric acid, lime, magnesia, iron, and silica, although neither of these substances can be detected there by means of the ordinary chemical tests. The presence of each and all of them, as well as that of potash and manganese, may readily be exhibited, however, by evaporating the solution to dryness, igniting the residue, and subjecting the ashes to analysis. Moreover, on dialyzing the ammoniacal solution, i. e. on placing between it and pure water a membrane so arranged that osmotic action may occur, it is found that the inorganic substances now in question readily pass through the membrane into the water, while the black matter remains behind. In the course of 36 hours, 86 % of all the ash-ingredients contained in such a solution passed through the membrane, while the water into which they diffused remained colorless and free from carbonaceous matters. Thus, presumably, would the constituents needed by plants pass into them by way of osmosis out of the organic solution. As obtained from some soils, Grandeau's black matter may contain no more than 2 % of ashes, while in other instances it may yield 60 %.

It would appear from the foregoing, that, under some circumstances, ammonia-water may dissolve from the soil phosphoric acid, lime, etc., that is, in so far as they are held in soluble combination by the organic matters. Indeed, carbonate of ammonia, such as might occur naturally in soils and manures, is better than ammonia-water, because it can act directly. Its carbonic acid combines with the lime which in the soil ordinarily holds the black matter in the insoluble state, and permits it to dissolve in the ammonia. From Russian black earth which contained 0.2 % of phosphoric acid, 80 % of this particular constituent was extracted in organic combination by means of ammonia-water.

According to Grandeau, black matter extracted as above from European soils may contain from 3 to 6 % or more of nitrogen, and Hilgard has found 5 % of nitrogen on the average in the black matter of soils from humid regions in the United States, but he has discovered that the black matter obtained from soils in the arid regions of California and other Western States is extremely rich in nitrogen. An average of almost 16 % of nitrogen was found in the humus of upland soils from California, and of 10 % in the humus of low-lying soils. The average amount of actual humus in the Californian soils was 0.75 % and 0.99 % respectively.

Grandeau is of opinion that carbonate of ammonia is of great importance as a solvent of food for crops. He believes that by means of it, acting in the manner above described, both farmyard-manure and many fertile soils may afford soluble inorganic food to crops, — the organic matter acting as a vehicle, so to say, for the transportation of the ash-ingredients. He urges, furthermore, that the fertility of soils is intimately connected with the amount of mineral matters that are contained in them so combined with organic matter that they can dissolve in ammonia. In barren moor-earth he found no more than mere traces of such materials, while Russian black earth was surcharged with them, and they were abundant in fertile garden-loam and in woodland-humus.

Too much Humus does Harm.

There is no need to say that the very qualities which make humus so valuable in soils that are naturally too dry, unfit it for application to moist soils. There are few things worse than humus upon a wet soil. In case any large quantity of it were put upon a moist soil, it would remain wet and cold, and would tend to increase the bogginess of the place

Whenever a field becomes surcharged with stagnant water, no matter from what cause, it will ultimately be covered with coarse, innutritious vegetation that can bear to grow with its roots immersed in water which contains no air. Moreover, when low-lying land is reclaimed, the sponginess or incoherence of the half-dried and imperfectly rotted peat is often detrimental to the growth of certain crops. Such land "heaves" badly in the winter, and crops sown upon it in the autumn may readily be thrown out. Several years may elapse before the land becomes firm enough for wheat, though it is a tenet of practical experience that some kinds of crops grow well upon newly reclaimed bog-land, notably oats, potatoes and buckwheat, while wheat and clover are apt to remain uncertain crops for many years.

In order to correct the looseness or sponginess, it is customary in many localities to dress reclaimed bog-lands with gravel and to plough this gravel under as if it were manure. Another way is to cover the drained bog with a layer of gravel several inches thick, and to spread manure and grow crops upon the new surface which has thus been obtained. This method seems to be of Celtic origin, and has frequently been made use of at one time and another in Ireland and England. In many situations, it is a great merit of the gravel layer that it acts to compress the bog-earth and to squeeze water out of it into the drains.

In recent years, the process of covering moor-land with gravel has been systematized in North Germany, and no little attention has been given to the scientific study of it. In cases where the layer of peat or moor-earth is from a foot and a half to three feet or more thick, in view of the fact that the country is absolutely flat, without any hills or knolls from which gravel might be transported to the moor-land on sleds or railway cars, the operations consist in digging deep, wide ditches at stated intervals, and spreading upon the surface of the moor the sand or gravel which is taken from the bottoms of the ditches. This layer of gravel is made 4 inches thick, and upon it the crops are grown.

Cases have been described where the ditches were dug at distances of about 75 feet one from another; they were 16 feet wide at the top, 11 feet wide at the bottom, and 4 or 5 feet deep. The black earth from the ditch is first spread upon the surface of the moor, and then the sand, gravel, loam, or clay taken from the bottom of the ditch is spread, in its turn, so that a layer of it four inches thick shall everywhere cover the moor-earth. A gravelly sand is said to be best; and, in general, the more gravelly the subsoil is, the better, provided it contains some clay. Pure fine-grained quartz sand is said not to answer nearly so good a purpose as gravel. The objection to fine sand is, not merely that it is blown away by the wind, but that it dries too rapidly by day and chills too quickly by night. In Ireland, particularly good results have been obtained by using limestone gravel. (A. Young.)

Oats may be sown at once upon the layer of gravel, and afterwards potatoes, roots, grain, and all kinds of forage plants. The main point is, that the layer of gravel is left permanently upon the surface of the land. It is never ploughed under, nor mixed with the moor-earth. Ordinarily, the gravel layer is ploughed no deeper than 4 inches. But from time to time, at rare intervals, when the surface land seems somewhat hard or incrusted, a subsoil plough is run through the beds, so as to loosen the soil without mixing one layer with another.

The layer of gravel is useful in several ways: It compresses the moor-earth and prevents it from passing into the light, incoherent, non-capillary, infertile condition which it would be apt to assume if it were to be cultivated directly in the ordinary way, immediately after draining, and if it were left exposed freely to the action of the sun and wind. One highly advantageous result is that the gravel tends to shield young crops from night-frosts in the spring. It lessens the evaporation of water from the soil, and cools off so slowly that the land is kept comparatively warm, while later in the season it ensures the coming up of a constant supply of capillary moisture even when the weather is so dry that drained moor-earth by itself might dry out. Hence a gravelled moor can safely be drained to greater depths than an ordinary moor.

It is noticed that when the gravel or sand has become dry at the surface this dry layer acts as a mulch to hinder the evaporation of water from the soil beneath. Thus the soil is kept moist and, so to say, mellow continually, and in such condition that the roots of crops find proper support and that the humus undergoes changes which fit it to serve as plant-food. Land thus covered with gravel admits of being tilled in the spring earlier than the adjacent uncovered land, and crops grown upon it are less liable to be thrown out by the frosts of winter. It is counted as an advantage that in preparing the gravelled moors for crops they need not be ploughed deeply. As was just now said, a furrow of four inches is deep enough. Such land is no longer in any danger of being destroyed by fire.

It is to be understood, of course, that the moor must be well drained before this method of cultivation, or any other, can be adopted. It is said that, as a general rule, the water-table should be kept some 3.5 or 4 feet from the surface of the soil, though for grass-fields it need not be so low as this. It has been found in practice that this method of reclaiming low-lying moor-land yields better crops than can be got from the moors by any other known process, and that the effects of the reclamation are sure and lasting. Whether or not it is the most economical of known methods is, of course, a totally different question.

One curious result of this method of cultivation, as ordinarily practised, is that humus may accumulate rapidly in the land. Analysis had shown from the first that the crops grown upon moor-land thus reclaimed are particularly rich in nitrogen; and, after some years' experience, it began to be noticed in certain localities that grain-crops are apt to lodge badly on beds that are 8 or 10 years old, and it appears that the trouble comes from too great fertility of the soil, i.e. from the accumulation in it of too much easily assimilable nitrogen. The practice had been to manure the fields much as any upland field would be manured, and here is where a mistake seems to have been made, for by using stable-manure too much mellow humus accumulates in the gravel layer.

Osswald, who has examined the soil from a number of these gravelled moors, found that the surface layer of gravel had become charged with a large amount of organic matter. Not that the gravel and the moor-earth from below had become mixed. On the contrary, the line of demarcation between the two kinds of earth was found to be surprisingly sharp, considering that twelve years had elapsed since the gravel was spread, and that arable crops had been grown upon the land continually. The trouble was, that the continued application of stable-manure and the increase of plant-roots had led to an actual accumulation of humus in the gravel.

Osswald did not find any surprising amount of nitrates, though he did find very large quantities of ammonia, and it was plain that there was present a far larger quantity of active nitrogenous manure in the soil than there was any need of. As the lodging of the grain had already shown, there was far too much of this nitrogen. Instead of becoming exhausted with cropping, the fields had become too fertile. That is to say, they were no longer competent to grow so great a variety of crops as they had been at first. They still did very well for grass, however. Some of the twelve-year-old beds yielded the best crops of ray-grass, cut over and over again for green fodder, they had ever given, though they had all along been well manured with dung, superphosphate, bone-meal, and Stassfurt potash salts.

Speaking in general terms, the continued use of heavy dressings of farmyard-manure on such land is not to be commended. Here assuredly, if anywhere, the use of a comparatively large proportion of mineral fertilizers, in conjunction with the dung, would be in order; for under proper management, the great store of natural nitrogen should be competent to supply the larger part of all the nitrogen which the crops might need. Of course, care would have to be taken, at first, to "sweeten" the original sour humus by liming or dunging the land, and at no time should lime, or superphosphate, or potash salts be applied in such large quantities as would be liable to hinder the nitrification of the humus in the soil. It was noticed long ago by German cultivators, even on bog-lands that have not been covered with gravel, but merely mixed therewith, that much more abundant crops of forage can be grown than of merchantable grain, and that it is not good practice to apply heavy dressings of dung to such land, because of the rank growth caused by it. Dressings of marl, used in conjunction with phosphatic and potassic fertilizers, have been commended for such land. Whenever, as in the case just now described, the gravel covering of the bog-land has become surcharged with humus, it would seem to be proper to grow upon it a succession of exhausting crops, without applying any nitrogenous manure, in order to take down the exuberant fertility; else a new layer of gravel might have to be laid down on top of the old layer, at enormous expense.

The great cost of covering a bog with gravel in this way limits the applicability of the process to countries where labor is abundant, although it is worthy of remark that cranberry bogs have long been made in this country much in the same way. But there is a modification of the process applicable to moors which are covered with but a thin layer of black earth, which might possibly be applied occasionally even in this country.

When the moor-earth is no thicker than from 8 to 16 inches, the

Germans get the top layer of gravel by bringing up the subsoil from just below by a system of trench ploughing. Three ploughs specially adapted to the purpose are run one after the other. The first plough turns a flat furrow 3 inches or so deep; the second plough stirs the sole of the first furrow to a depth of 12 or 16 inches; and the third plough throws up at least 6 inches of the loosened gravel, to cover the original sod. The idea is much the same as before, viz. to cover the humus with gravel. These ploughing operations are carried out in summer and autumn. Next spring the furrows are levelled with a heavy harrow, and oats are sown upon the land.

The process is interesting enough and instructive enough to demand attention when considered merely as a method of cultivation; but the purpose of citing it here is to indicate how rapidly humus, i. e. nitrogenous humus, may accumulate in a soil when the conditions are favorable for such accumulation. As bearing upon this point, reference may again be made to the fact of observation, that in ordinary European farm practice only a moderate proportion of the nitrogen applied to the land in the form of manure or fertilizers is recovered in the crops.

Some Moors are Poisonous.

On the low-lying German bog-lands to which this system of cultivation has been found well adapted, it commonly answers an excellent purpose provided the moor-earth is not actually poisonous at the start. But, as has been explained already, it will be well that both the moor-earth and the gravel should be free from sulphides of iron, lest, when air gains access to these compounds, there should be formed sulphate of iron or free sulphuric acid; and lest, through the action of carbonic acid, sulphuretted hydrogen should be set free.

It has been noticed occasionally on some moors which have been gravelled, that crops are apt to fail on those spots and places to which sulphuric acid or ferrous sulphate have been brought, by the capillary movement, in quantities large enough to be injurious to plants. In his research as to the causes of sterility in certain soils, Voelcker long ago cited instances where much harm had been done through the presence in the soil of no more than half of one per cent of the iron sulphate, and he found that nothing whatever grew on land which contained little more than one per cent of the sulphate. Since ferrous oxide and ferrous silicate are quite insoluble in water, it is not to be supposed that either of these substances can of itself be injurious to plants, though the presence even of these products of reduction may serve to show that the soil is not adequately aerated.

A completely barren sandy soil, of strongly acid reaction, examined by Voelcker, contained 1.05 % of ferrous sulphate and 0.56 % of black sulphide of iron; which, as he remarks, "is even in the smallest proportions most pernicious to plants." Another soil, taken from an infertile field on land reclaimed from the Haarlem Lake in Holland, exhibited a strong acid reaction and contained — beside 1.72 % of sulphate of lime — 0.74 % of ferrous sulphate, 0.71 % of ferrous sulphide, and 1.08 % of sulphuric acid united with oxide of iron as basic sulphate of iron. Although this soil was rich in nitrogen, phosphoric acid, potash and other ash-ingredients, it was completely unproductive when deeply tilled. So long as the field had been lightly scratched at the surface, it produced scanty though still remunerative crops, but on being ploughed deeply no crops could be got from it, and no good was done by applying farmyard-manure. "By the deep cultivation, sulphide of iron was turned up, and air was admitted into the soil more freely, which had the effect of oxidizing the iron pyrites and changing it into green vitriol. . . The proper remedy for such a state of things is a heavy dressing of lime, marl or chalk; for quicklime, or the lime in marl or chalk, decomposes sulphate of iron, and uniting with the liberated sulphuric acid, gives rise to gypsum — a useful fertilizer — and to oxide of iron, which occurs in all fertile soils. In the case before us, my recommendation to apply a heavy dressing of lime was adopted with complete success." Another soil, from land that had been reclaimed from the sea in England, and which was poisonous to plants because of the presence of ferrous sulphate, was found to contain 1.39 % of this substance and 0.78 % of ferrous sulphide.

The following analyses reported by Maercker relate to moorland that had been covered with gravel in the manner above described. Bed No. I bore good crops; but on bed No. II nothing would grow from the first; on the contrary, a crust that contained iron compounds formed at the top of the four-inch layer of sand. Bed No. III gave a good crop of wheat in 1871, but horse-beans failed upon it in 1872. No. IV was from a wild moor; the sample was taken from a bare spot in a birch-wood on which no vegetation had been seen for 25 years.

It appeared from the analyses that all the specimens contained enough potash, lime, phosphoric acid, and other ash-ingredients, to have enabled the land to bear crops; but in addition to these things there was a good deal of iron, and in some case there was the poisonous ferrous sulphate also: —

100 Parts of the dry Earth contained	I. Continually Fertile.	II. Not Cultivable.	III. Cultivable at first.	IV. Bare for 25 Years.
Iron, reckoned as ferric oxide (Fe_2O_3)	4.830	7.540	6.580	6.390
Iron in the form of ferrous oxide (FeO)	1.500	1.880	1.780	2.740
Iron that was soluble in the form of ferric oxide	0.226	0.999	0.319	0.066
Iron that was soluble in the form of ferrous oxide	0.000	1.349	0.298	0.395
Iron that was soluble, all reckoned as ferric oxide	0.226	2.498	0.650	0.505

It appears from the analysis No. I that a small amount of ferric sulphate did no particular harm, while the ferrous sulphate of II, III, and IV poisoned the land. The analyses enforce the propriety of using bone-ash, phosphatic slag, floats, or greensand, and muriate of potash on such land rather than gypsum, or sulphate of potash, or superphosphates that contain gypsum; for by the reduction of the sulphates in the nonaerated moor-earth sulphide of iron could readily be formed, and through the oxidation of this sulphide the poisonous ferrous sulphate might result. Maercker urges that by liming the soil, so that it shall be charged with calcic humates, the noxious ferrous sulphate would be decomposed as fast as it formed. Contrary to what has sometimes been taught, the presence of insoluble ferrous compounds in the soil did no harm. It was only when soluble ferrous salts, such as copperas, were at hand that the crops suffered.

One point to be noticed is that gravel taken from beneath bog-earth will be much more likely to contain hurtful sulphides of iron than that taken from upland banks and hills, to which air has always had access. Generally speaking, gravel that can be run down upon the bog-land from a neighboring hillock will be better suited for covering purposes than that which has to be dug out from wet ditches. In a case where the bog-sand used for covering contained sulphide of iron, quicklime was strewn upon part of the field, and excellent crops of barley and of oats were obtained there at once, while on that part of the field which received no lime the first crops failed. The land became fertile, however, after the sand had been exposed to the weather for a year or two.

Different kinds of Moor-earth need different Treatment.

Experiments made by Fleischer and others on high-lying moors, have shown that the process just now described is not applicable in certain cases. It is plain, for that matter, that there are several different kinds of moor-earths and bog-earths, and that methods of treatment proper for one kind may not be proper for other kinds. Some kinds of sour humus do not readily become sweet and mellow when covered with a layer of gravel and dressed with artificial fertilizers, not even when the land has been thoroughly drained, while the admixing of such humus with sand and with night-soil may be highly judicious. Even when the sour land was limed before applying the layer of gravel, the crops obtained were inferior to those got from the fields where sand and night-soil had been plowed under. But on applying night-soil to the land covered with gravel, good crops were obtained. All of which goes to show the importance of assimilable nitrogen and the necessity of treating the lands in such manner that the nitrogen of the inert humus shall become available. As bearing upon this point it should be said that experience teaches that the original grass, or other herbage which may be growing upon the moor, had better be destroyed before proceeding to cover the land with gravel. When practicable it may even be well to cultivate the land somewhat before gravelling it, in order to bring the humus into good condition by the action of air and of micro-organisms, and by means of applications of lime or of marl. Fleischer has reported a case where there was harvested, per Morgen, from moor-land which had been: —

	Centner of Rye.	
	Grain.	Straw.
Mixed with sand	8.8	17.7
Covered with sand, without previous cultivation . .	4.8	12.9
Covered with sand, after cultivation and fertilization	10.9	19.0

Carsten, in Holland, tried the experiment of growing oats on contiguous plots of moor-land, each $\frac{1}{8}$ of an acre in area, some of which had been reclaimed by covering the land with gravel, as above, while others had been reclaimed by mixing gravel with the moor-earth. In every instance where the gravel and moor-earth were admixed, the crops obtained were inferior to those from the gravel-covered land, as will appear from the following table: —

Manure on 1-5 Acre	Cost of the Manure.	Bushels Oats from 1-5 Acre of Covered Land.	Mixed Land.
55 lb. rectified guano	$4.00	6.13	5.56
55 " steamed bone-meal			
33 " sulphate of potash and magnesia			
66 " plain Peruvian guano	4.25	8.51	6.13
55 " steamed bone-meal			
33 " sulphate of potash and magnesia			
33 " nitrate of soda	3.80	4.26	1.94
66 " steamed bone-meal			
83 " sulphate of potash and magnesia			
110 " rectified guano	3.80	9.37	6.81
Same money value of plain Peruvian guano	4.00	11.08	7.66

It was thought that most of the nitrate of soda was washed away by rains, and that better results might have been got from this material by using it in larger quantity and applying it at intervals as a top-dressing.

Simultaneously with the tabulated experiments, two plots were manured with night-soil from city cesspools applied in such quantity that the cost was $14.87 for each of the ⅕ acre plots. There were harvested from these two plots 12.14 and 11.35 bushels of oats respectively. It is noticeable, both as regards the night-soil and the guano, that the largest crops were obtained from the manures most likely to be charged with the ferment which would cause nitrification of the moor-earth. It will be noticed also that $20 worth of plain guano to the acre gave almost as large a crop (55½ bushels to the acre) as night-soil applied at the rate of $74 worth to the acre.

Increase of Humus in Pastures.

It is not alone in low-lying bogs that humus may accumulate. Such increase is often visible to the eye in pastures and mowing fields, and the experiments of Lawes and Gilbert have proved the correctness of the popular belief that organic matter does not ordinarily go to waste in such situations as fast as it is formed or brought there. Thus, in cases where arable land had been seeded down and subsequently used as pasture or as a hay-field, it was found, after the lapse of years, that the proportion of nitrogen in the soil had increased appreciably, as will be seen in the following table: —

Percent of nitrogen in arable land	0.140
" " " " pasture 8 years old	0.151
" " " " another pasture 18 years old	0.174
" " " " Dr. Gilbert's hay-field 21 years old . .	0.204
" " " " " " " 30 " " . .	0.241

In the case of Dr. Gilbert's hay-field, it was estimated that the increase of nitrogen in the surface soil during thirty years had been at the rate of about 50 lb. per year and per acre. Some of this nitrogen came from stable-manure which was applied to the land every other year, but some of it evidently came from the air, through leguminous plants or from the subsoil.

Humus cools Soils.

The influence of dark-colored substances upon the temperature of the soil has already been insisted upon; and it may possibly be true that humus sometimes tends to make a soil warmer by virtue of its color, but this is not its usual mode of action. On the contrary, it chiefly serves to cool the soil, and it often does good in this way; i.e. by regulating the temperature of the soil, by means of the water which it holds. At mid-day, in summer weather, the surface of a mere sandy soil may become so hot that the hand can hardly be held against it. But if such soil be charged with humus, through abundant dressings of long manure, or by the addition of peat, it cannot readily become so hot by the action of the sun's rays; for the water which the humus sucks up from the subsoil, and absorbs from the air which rises out of the subsoil will slowly evaporate, and in so doing will consume so much heat that the soil itself will remain comparatively cool.

Fixation of Bases by Humates.

Some reference has already been made to the power of humus to absorb and hold the vapor of ammonia and of carbonate of ammonia, and the subject will again be referred to hereafter. It is to be noticed, however, that by virtue of the humic acids contained in it humus can combine with lime and magnesia, and with the bases contained in alkaline substances such as the carbonates and soluble silicates of potash and soda, i. e. humus can absorb and fix and hold these basic substances. The humates of lime and of magnesia, like most other humates, are wellnigh insoluble in water; but potash and soda, when present in excess, form soluble humates. In the soil, however, these basic alkaline humates quickly unite with other humates of metals or earths, and form double salts which are only very difficultly soluble.

Detmer describes a double humate of lime and ammonia as being soluble in rather more than 3,000 parts of water, and one of iron and ammonia as dissolving in 5,000 parts of water, at 66° F. The acid humates of potash and soda, such as would naturally form in any soil rich in humus on the addition of a small quantity of an alkaline carbonate, are wellnigh insoluble in water.

It is noteworthy that some varieties of humus are capable of absorbing a larger quantity of potash, soda, or ammonia from the carbonates of these substances than from the caustic hydrates. Thus S. W. Johnson found that a peat from New Haven could absorb 1.3% of ammonia from a solution of carbonate of ammonia, but only 0.95% from a solution of caustic ammonia. It is not improbable that this particular peat may have contained some humate of lime upon which caustic ammonia might have comparatively little action though it would be decomposed readily by carbonate of ammonia with formation of humate of ammonia and carbonate of lime. Several chemists have noticed that soils rich in humus may absorb alkalies more forcibly after they have been limed, or mixed with carbonate of lime, but in this case the improvement is manifestly due to the formation in the soil of a quantity of humate of lime with which the added fertilizers can react by way of double decomposition.

In case a field to be fertilized contains free humic acid, a preliminary liming would neutralize this substance, and by forming humate of lime would prepare the way for the fixation of potash or phosphoric acid and other fertilizing matters, such as would naturally be applied to the land in manures. It is to be noted, however, that this remark applies more particularly to low-lying soils, and especially to soils that are said to be "sour"; for in good humus, such as exists in garden loam, or in almost any really fertile field, the humic acids are not free, but combined with one base or another to form salts of the humic acids, or, as the common saying is, "humates" which are already competent to fix the constituents of fertilizers. It may be said with truth of many fertile countries, and especially of regions where limestone abounds, that highly cultivated soils ordinarily contain no free acid other than carbonic acid. It was remarked by Voelcker long ago, that "Good and fertile soils either have no effect upon red or blue litmus paper, or they show a slight alkaline reaction, i. e. in a wet condition they restore the blue color to reddened litmus-paper," because of the presence of bi-carbonate of lime, which, as is well known, exhibits an alkaline reaction. It is to be observed none the less, that in many districts of no great fertility, as in New England and in other non-calcareous regions, cultivated soils are apt to exhibit a faint acid reaction.

In ordinary soils the ingredients of humus are so circumstanced that only some traces of them can be dissolved out of the soil by water; but from peat, leaf-mould, and even from rich garden-earth which through fermentation or decay has become charged with carbonate of ammonia, water will extract an appreciable amount of soluble matter, which is sometimes in the condition of humate or ulmate of ammonia. There can be no question that these solutions may do good service sometimes, both by reacting upon various matters in the soil and rendering them soluble and available as plant-food, and by being converted into nitrates by fermentation and oxidation.

Humates insoluble in Saline Solutions.

An interesting fact, noticed by Knop, is, that the humates in the soil are much less soluble in saline solutions than they are in pure water. Thus, if a quantity of loam be treated with successive portions of water, the first filtrate will come through almost colorless, while the succeeding portions of the filtrate will be decidedly colored from the presence of dissolved organic matter. That is to say, as soon as the saline matters natural to the soil have been rinsed away by water, certain compounds of humic acids will dissolve in fresh water to an appreciable extent. It would seem, therefore, that a new solvent force must be brought into action in the soil when the conditions are such that solutions of humates can appear; as, for example, after continuous rain.

A familiar example of the insolubility of humates in saline solutions is seen in limestone countries where the "hard" water of the wells is apt to be particularly clear and colorless, thanks to the presence of soluble bi-carbonate of lime. So, too, Knop's observation serves to explain how it is that in certain regions the waters of brooks are sometimes more or less highly colored, while in other localities brook waters are free from color. Thus in many brooks of New England and of Scotland, which flow from bogs, highly colored waters will be noticed after rain, as in the water of the Dismal Swamp of Virginia constantly, and in several tributary streams of the Rivers Amazon and Orinoco. As Muntz and Marcano have explained, these dark-colored South American rivers contain very little mineral matter in solution, and they owe their color to the presence of free humic acids which have been formed by the decomposition of vegetable matter in a non-calcareous, granitic soil. When the "black" water of the streams now in question flows into clear rivers the coloration speedily disappears because the humic acids unite with lime which is held dissolved in the colorless water, and the humic-lime compound quickly settles out. It is to be noticed that these black or coffee-colored waters are not turbid. They are as clear as wine. But like wine they are colored by the presence of dissolved organic matters. For the agents which act to clarify turbid waters see "flocculation" in the index to the third volume of this book.

Alkaline salts, such as the carbonates of potash, of soda and of ammonia, which freely dissolve humus, are of course exceptions to the foregoing rule; and so are solutions of the phosphates of potash and of soda, and especially phosphate of ammonia, for they dissolve humates somewhat in the same way that the alkaline carbonates dissolve them. It has even been noticed, both by Schulze and by Knop, that the solutions of humates which appear, as above described, on percolating soils with water after they have been washed free from saline matters, contain appreciably larger quantities of phosphoric acid than the first filtrate does. By direct experiment, Knop found, that, as a rule, the solubility of humates is very much less in solutions of sulphate of potash, or of the nitrates of potash or lime, than it is in mere water.

According to Detmer, humic acid itself is much less soluble in solutions of chloride of potassium, chloride of sodium, and nitrate of potash, than it is in pure water. The mineral acids, i. e. hydrochloric, sulphuric, and dilute nitric acids, dissolve no more than traces of humic acid, though phosphoric acid can dissolve rather more. Detmer determined that one part of humic acid dissolves in 8,333 parts of water at 43° F. and in 3,571 parts at 65°. Dry humate of ammonia, on the contrary, is readily soluble; one part of it dissolves in 2¼ parts of water.

Few, if any, Agricultural Plants feed upon Humus.

Much has been said and written in times past upon the question whether or not crops can feed upon humus directly, i. e. as to whether humus can be taken in, as such, by the plants and used as food. In recent years, the point of view of investigators has changed so completely that it is not easy to put one's self in the position of the earlier experimenters or to do full justice to their theories. As has been set forth in the chapter on symbiosis, there are now some reasons for believing that humus may occasionally serve a useful purpose for feeding various kinds of crops through the intervention of fungi, which while living upon the roots of plants and feeding upon the plants and upon the humus of the soil, can convey both carbonaceous and nitrogenous matters from the humus to the plants.

There are, as is well known, various kinds of plants of low orders which can feed directly upon humus, upon decaying vegetable matters, or upon dead plants; but it is a familiar fact that most agricultural plants (excluding mushrooms from the category) can grow perfectly well in the absence of humus. This fact is illustrated by experiments which have been made by way of water culture, and by those made with factitious soils. Boussingault's sunflower, for example, grew to perfection in a soil which had been purposely freed from carbonaceous matter, excepting what was contained in the seed from which the plant sprung; and similar results have been obtained by many other observers. Beside laboratory experiments, there is the example of successful agriculture in many sandy countries, where fertility has been obtained, even from the first, by means of irrigation. According to Gasparin, crops of peculiar excellence are grown on certain volcanic ashes of Vesuvius (*rapilli*) which contain some 12 % of potash, but no organic matter.

The first vegetation on the globe must have grown without the aid of humus, even more certainly than is the case with the plants of low orders which are now sometimes to be seen growing upon bare rocks, or of the sea-weeds which are seen growing in the water. And yet, as has been said already, the presence of humus in a soil may perhaps be of great practical importance for the support of microscopic organisms, and so, indirectly, for the nourishment of some kinds of crops. Even before the doctrine of symbiosis had been formulated, several accurate observers had insisted that although grain crops appear to be quite independent of the presence of organic matters in the soil, certain other crops — notably root crops such as turnips, and mangolds, and sugar beets, and rape — are, to all appearance, often materially benefited by manure rich in carbonaceous matters, and notably by humus.

It is to be said, moreover, that although humus may often be dispensed with and though there is no reason for supposing that it plays any important part directly as a source of the carbonaceous food of agricultural plants, it is not improbable that some of the soluble portions of humus may be taken up by plants from the soil. Detmer has found indeed, that, although humic acid and the humates are colloid bodies and non-diffusible, apocrenic acid and its salts, which result from the oxidation of humus, are easily diffusible, and are in fact taken up by pea-plants.

Petermann also found, on placing several different kinds of loams on parchment paper, the other side of which was kept in contact with water, that not only inorganic matters (viz. lime, magnesia, iron, potash, soda, and sulphuric, hydrochloric, silicic, phosphoric, and nitric acids) passed out from the loam through the paper by way of osmose, but that appreciable quantities of soluble organic matter also diffused out from the loam into the water. He found that quantities of matter ranging from 0.04 to 0.26 grm. passed out from 100 grm. of loam into the water in ten days' time, and that from 0.01 to 0.18 grm. of this matter was organic. In fact, the amounts of organic matter which passed through the membrane varied from 20 to 69 % of the total matter which passed through.

Petermann remarks, that this organic matter is neither humic acid, nor humate of ammonia, nor the so-called black matter of Grandeau, all of which substances are colloid and non-diffusible. It recalls rather the neutral soluble organic matter, "analogous to dextrin or sugar," which was extracted from loams long ago by De Saussure, and by Verdeil and Risler.

Plants can Feed on Organic Matters.

Chevreul insisted long ago that plants can take in blood as such and put it to profit, and it was shown subsequently that they can feed upon various nitrogenized carbonaceous matters, such as urea, for example. There are in fact some kinds of plants which habitually capture insects and feed upon them. It has been shown moreover by the experiments of Van Tieghem, that, for the support of germinating seeds, it is not essential that the cellular structure of the store of nutritive matter which naturally surrounds the germ or embryo of the seed should be preserved intact. That is to say, it is not strictly necessary, in order that a seed may grow to the condition of a self-sustaining plant, that there shall be an actual, organic, cellular connection between the embryo and the supply of nutritive matter. He detached the embryo of Mirabilis (Marvel of Peru), from the remainder of the seed, ground the latter, together with a little water, to paste in a mortar, and placed the embryo in a ball of this paste under conditions suitable for germination. The embryo sprouted in due course and grew as well as if it had been left in an unmutilated seed. On substituting a paste of buckwheat flour for the ground-up seeds, the experiment succeeded as well, and in still other experiments where potato starch was used it appeared that a considerable portion of this material was consumed by the young sprout, especially when small quantities of nitrates, phosphates, etc., had been mixed with the starch.

It is now known very well that as a matter of fact most plants if not all plants can be supported in some part by solutions of various organic substances. Boehm has shown that starch forms readily, even in the dark, in the green leaves of many different kinds of plants when cut off from the parent stem and immersed in a solution of sugar, and this observation has been repeatedly verified. The researches of A. Mayer, E. Laurent, Bokorny, and others, have proved that the green leaves of many plants can take in sugars (of various kinds) and transform them to starch; and similar results have been obtained when leaves freed from starch were supplied with mannite, dulcite, glycerin, methyl alcohol, methylal, ethylenglycol, etc. In one of Bokorny's experiments, Lemna plants which were kept in the dark, and fed with a one-thousandth solution of glycerin, as well as with ash-ingredients, doubled their weight in the course of 16 days. A very considerable increase in weight was noticed also in the case of Cladophora plants fed with the glycerin solution. In another trial, Cladophora plants kept in the dark and supplied with mineral food, and a one-thousandth solution of methyl alcohol nearly doubled their weight in a fortnight, as compared with plants similarly situated which got none of the alcohol. Bokorny insists that in all these cases where plants kept in air free from carbonic acid are fed with organic matter, the starch formed from the organic matter is seen to appear in the chlorophyl grains and not outside of them.

Acton also found that plants or shoots grown by way of water-culture, and deprived of starch by keeping them in air free from carbonic acid, formed starch when an extract of humus — prepared by digesting leaf-mould in dilute alcohol and filtering — was supplied to their roots, though not when the extract was applied to their leaves. Glucose in 0.5 % solution was more readily taken up by the roots than cane-sugar was. The roots withdrew all the glucose from a 1 % solution, and remained healthy while starch was produced. Starch was formed in these plants when soluble starch was applied to their leaves, but not when applied to the roots.

As has already been set forth in the chapter on Symbiosis, it is well known that fungi — such as mushrooms, moulds, and yeast — readily assimilate carbon from the organic matters on which they feed, and it might be said with truth that the higher orders of plants are really supplied with carbonaceous matters in much the same way as the fungi, since the action of the chlorophyl grains is merely to change the carbonic acid of the air into carbonaceous compounds which speedily mix with the juices in the plant and pass about from one part of the plant to another for the purpose of feeding it.

Schmidt has shown that neutral fats and oils and even free oleic acid serve well as food for various species of moulds and for mosses, and that oil is absorbed by many germinating plants also, such as peas. According to Loew, the following chemical substances — used in neutral or faintly alkaline solutions — can serve as sources of carbon for the production of vegetable cells, viz. alcohols, phenols, organic acids, ketones, aldehydes, carbohydrates, ethers and esters, and many alkaloids.

Formation of Starch from Formic Aldehyde.

It has been remarked already in the second chapter of this book, when treating of the fixation of carbon by plants, that possibly the organic substance known as formic aldehyde (COH_2) might result from the simultaneous decomposition of carbonic acid and water in the chlorophyl grains and serve as material for the formation of sugar, starch, and the various other proximate principles of the plant. This idea has been subjected to the test of experiment, and there are good reasons for believing that it is well founded. Formic aldehyde when prepared artificially outside the plant, and applied as such, acts on vegetation as a poison and consequently cannot be used for the experiments now in question. But there is a non-poisonous compound of formaldehyde with sodium sulphite — known as formaldehyde-sulphite of sodium, or as oxymethyl-sulphonate of sodium — which has been employed with success by Loew and by Bokorny. The supposition is that this substance is decomposed so slowly and gradually by the protoplasm in the plant-cells that the formic aldehyde changes to sugar or starch, or what not, as fast as it is set free, and that not enough of it to injure the cells is produced at any one moment.

Specimens of the filamentous alga spirogyra were deprived of their starch by keeping them in the dark for a day or two, or in solutions that contained no potash, and were then placed in a solution of the formaldehyde compound to which a little phosphate of potash had been added. On exposing these plants to light, in air that contained no carbonic acid, it soon appeared that an abundance of starch had formed within the plants, while in control experiments, no starch was formed in plants similarly situated to the foregoing excepting that they had not received any of the compound of formic aldehyde. Similar experiments were tried also and corresponding results were obtained with another non-poisonous compound, methylal, which readily yields formic aldehyde as a product of its decomposition.

It is to be said furthermore that, by resorting to purely chemical means, several chemists have obtained from formic aldehyde substances which resemble sugar, and there is no longer any improbability in the idea that this compound may really serve as a means of feeding plants.

Loew has suggested also that the nitrous ferment when acting upon ammonia may not oxidize this substance completely, as represented by the equation

$$2\ NH_3 + O_6 = 2\ HNO_3 + 2\ H_2O,$$

but that the oxidation may be incomplete, as in the equation

$$2\ NH_3 + O_4 = 2\ HNO_2 + H_4,$$

and that the nascent hydrogen may be put to use in the protoplasm of the ferment fungus for the reduction of carbonic acid:—

$$CO_2 + H_4 = COH_2 + H_2O,$$

and that the formic aldehyde thus produced may serve for the formation of carbohydrates and albuminoids. From all of which it appears that there was no improbability in the old supposition that organic matters taken into the plant from the soil might serve to nourish it in respect to carbon. On the contrary, the familiar fact of observation that many plants — which have few or no chlorophyl grains — are nourished by soluble carbonaceous matters taken in through their roots seemed to indicate that all plants might take carbon from the soil on occasion.

It is a matter of experience, however, that the amount of carbonaceous matter thus taken in by the roots of agricultural plants is, under ordinary circumstances, too small to be worth considering; though there are still some exceptional cases, as, for example, that of the smart-weed and other rank-growing plants that flourish on the edges of barnyard pools, where the amount of soluble carbonaceous matter absorbed may possibly be sufficient to exert an appreciable influence on the growth of the plant. But it must always be remembered that it is the nitrogen of the dung liquor that causes the rank growth of weeds, which attracts attention to them. (Compare "How Crops Feed," pages 232 to 238.)

Albuminoids also may be derived from Formaldehyde and Ammonia.

According to Loew, it is probable that albuminoids are formed by way of condensation from the group CHOH (together with ammonia and sulphur) in a manner analogous to that in which carbohydrates are formed, and this view consists with the well known fact of the mutual convertibility of albuminoids and amids. Loew suggests that by the triple condensation of 4 CHOH, in presence of ammonia, there might be formed the aldehyde of aspartic acid $C_{12}H_{17}N_3O_4$, which, when subjected to further condensation under the influence of reducing agents, in the presence of assimilable sulphur, would be competent to produce albumin:—

$$6\ C_{12}H_{17}N_3O_4 + 6\ H_2 + H_2S = C_{72}H_{112}N_{18}SO_{22} + 2\ H_2O.$$

It is to be presumed also that oils and fats are formed in plants by processes of condensation analogous to those which produce sugar and starch.

In experiments made by Loew, it was found that albuminoids were formed in abundance in spirogyra plants that were grown in the dark in a solution that contained a compound of formaldehyde and nitrite of potash. Certain bacteria also grew rapidly in solutions which contained the formaldehyde compound as the sole source of carbonaceous food. The suggestion has been thrown out that perhaps the presence of potash salts may promote the condensation of aldehyde groups, as above set forth, though it has been observed in the case of certain fungi, that cesium and rubidium serve the same physiological purposes as potassium.

Can Humus Feed Plants Indirectly?

As a substitute for the old so-called humus theory above alluded to, it was taught at one time that although humus may not nourish plants directly, or be absorbed and assimilated as such, it is nevertheless extremely useful as a slow and constant source of carbonic acid to be absorbed by the roots. The idea was, that, like leaves, roots could absorb carbonic acid, and that they could extract from the soil the carbonic acid which is generated there by the oxidation of the humus. But this supposition was disproved by the experiments of Corenwinder, already alluded to, who showed that, far from being absorbed by the roots of plants, carbonic acid is continually given off from the roots. Moll found, moreover, that starch was not formed in the leaves of plants that were kept in atmospheres free from carbonic acid while carbonic acid was supplied to their roots. Indeed, starch was not even formed in individual leaves kept in atmospheres free from carbonic acid when the other leaves of the plant were abundantly supplied with this gas. Nor was starch formed in parts of leaves that were kept in air free from carbonic acid while the rest of the leaf was supplied with it. No appreciable increase in the rate of formation of starch could be detected in the leaves of plants growing in the open air when carbonic acid was supplied to their roots.

The experiments of Dehérain and Vesque in like manner go to show that no carbonic acid is taken in from the soil by plants to be used by the leaves. These observers were unable to detect any evolution of oxygen from the leaves of plants unless carbonic acid was supplied to the leaves directly from the air. Of course, much carbonic acid, formed by the oxidation of humus in the soil, is continually thrown into the air, as has been already explained, and is there put to profit by the leaves of plants.

CHAPTER XXX.

DUNG AND URINE. — FARMYARD-MANURE.

The fertilizing power of animal excrements depends so nearly upon the quality and quantity of the food which the animals have eaten that it is difficult to arrive at just conclusions as to the average chemical composition of any one kind of dung, or to frame precise rules for its preservation and application.

The really useful constituents of the excrements are certain compounds of nitrogen, of phosphoric acid and potash together with small quantities of compounds of lime, magnesia and soda. These substances are known to act either directly as plant-food, or as means for improving the water-holding power of the soils to which manure has been applied. Several of these matters are held in solution in urine, which is on this account a fertilizing agent of quick action. All of the constituents of urine are in a condition to be put to use immediately by growing plants. Dung, on the other hand, i. e. the dung of cows, horses and sheep, consists for the most part of undigested remains of vegetable matters which the animals have eaten, and since these refractory materials decompose but slowly in the soil, the plant-food contained in them can only gradually become available. It is true, moreover, that mere dung contains no very large amount of humus-producing materials; though, as ordinarily applied to the land, in the form of farmyard-manure, it is usually mixed with much straw or other organic matters which have served as bedding for the animals, or been rejected from their cribs.

It has been found by experiments, that the weight of the dried excrements either of horses or cows amounts on the average to a little less than one-half the weight of the dry matter in the food consumed. The rest of the food has either gone out from the body in the form of carbonic acid or water, or been converted in the body into flesh, milk, wool or the like.

As regards the inorganic matters of the food, the whole of them do, of course, go into the manure. It is plain enough, at the first glance, that, in so far as the inorganic matters are concerned, a herd of cattle fed upon grain (which is rich in phosphoric acid) will yield manure of far higher value, as regards phosphoric acid, than a similar number of cattle fed only on the straw from which the grain was threshed. Even if this second parcel of cattle were fed upon straw and roots, the value of the manure, as regards the phosphatic constituents, would still be less than that from the grain-fed beasts.

But as regards the nitrogen compounds, which have on the whole a much higher money value than either of the other constituents in the manure, the question is far less simple. Much depends, indeed, upon the quantity of the food eaten, as well as upon its composition and quality. When animals are allowed to eat their fill of rich food which contains much nitrogen, comparatively large quantities of the nitrogenized products of digestion will pass through them, and their manure will be exceptionally rich in nitrogen.

On the other hand, it would be easy to maintain cattle, even in tolerable condition, on such a ration of straw admixed with a little grain or with small additions of roots, that the dung, though rich in inorganic materials, would be exceptionally poor in nitrogen. Indeed, it is known to be possible to substitute pure cellulose (paper-maker's pulp) for the straw in this experiment, and so to reduce the proportion of nitrogen in the dung still lower. But, by feeding liberally with oil-cake, cotton-seed-meal, or other highly concentrated fodder, it is easy to obtain dung rich in nitrogen as well as in ash-ingredients. Practically, the amount of nitrogen in the food is of paramount importance in determining the quality of the manure. The larger part of the nitrogen compounds in food undergo changes in the bodies of animals which increase their efficiency as fertilizing agents.

One good illustration of the influence of food on the quality of manure is seen in the well-known difference between the dung of grain-fed horses, and that of horses fed solely upon hay or grass. Marshall, writing in 1796, says: "Beside his unfair method of feeding (on particular patches of grass), the horse is disliked in pastures, on account of the worthlessness of the dung of horses at grass. This appears somewhat paradoxical when the superior value of their dung in the stable is considered. But the idea is not confined to this district [Yorkshire] nor to England alone; it prevails in America, and more or less in every place where husbandmen observe attentively."

Generally speaking, however, the manure obtained from neat cattle will be found to vary more widely as to its composition than that obtained from horses, since the food of cattle is usually subject to much greater differences than the food of horses. Indeed, it is on this account no easy matter to arrive at just conclusions as to the average composition of the manure of cattle.

Influence of Food on Manure.

Everything goes to show how intimately the question of preparing manure is connected with that of feeding cattle. On every farm there must evidently be some one particular style of feeding, which shall give, all things considered, the best possible economic results for that farm.

In one place it will be good policy to expend the food in such manner that the largest possible proportion of the nitrogen in it shall serve merely to maintain the animals, while in another place, where the conditions and requirements are different, it may be best to have a part of the nitrogen pass through the animals to the credit of the manure, even if it should happen that a part of the food were not digested at all.

It must often happen that the backwoodsman or newly settled immigrant, no matter where, will be in the predicament first mentioned. Suppose, for example, that at the beginning of winter he finds himself encumbered with several head of cattle in rather poor condition, and that he has but a scanty supply of fodder. He has no means of disposing of these cattle or of buying fodder for them; and they are by no means fat enough that any advantage could be gained by salting down their flesh. In this event, there can be no question that the farmer should expend what fodder he has in such wise that the largest possible proportion of the nutrient matters in it, woody fibre included, shall go to maintain the animals. The aim will be to economize food to the utmost, without thought of the manure. Any rich food, such as English hay or refuse grain, that may be at hand, will be doled out little by little, as an addition to and reinforcement of the coarse swamp-hay and "browse," by means of which the appetites of the animals are appeased. But the dung from such a stable would compare very unfavorably with that from a parcel of cattle fatting for market, and consuming as much oil-cake, for example, as they can well be made to eat.

The case of the half-starved cattle here mentioned is by no means an uncommon one. It must occur every few years, and especially after dry summers, in all Northern countries where the winters are long, and where there are many small farmers. It may be seen here in New England not infrequently when young cattle are pulled through the winter on rather inadequate rations of bog-meadow hay, or even upon coarser forage than that, reinforced with as little of better kinds of foods as may suffice to keep the animals alive. It does not follow, in the least, that the practice is an unphilosophical one. On the contrary it is, generally speaking, sensible and praiseworthy in a land of rocky pastures, where not a few farmers can keep in summer many more cattle than they can provide rich food for in winter.

Of course, the poorly fed animals must not be brought too near the starvation point. But this consideration is beside the present question. The point to be urged now is simply that the dung from the half-fed cattle cannot, by any possibility, be very rich.

Twice-eaten Fodder.

To see this argument reduced to its lowest terms, we may turn to an old Norwegian custom which enabled the peasants to go so far as actually to use their supply of hay twice over. Many travellers have noticed the practice. The following description of it is quoted from Mr. Laing's "Residence in Norway," London, 1859, page 272. Under date of February 11, he says: —

> "I saw this forenoon a piece of rural management which will scarcely be believed. The stock of this farm is 30 cows and 16 horses. The latter, of course, get no grain. A man came out of the stable with as much horse dung as could be heaped on his spade, and laid it down on the snow. He brought one spadeful after another till the stable was cleaned out, and he placed each spadeful in a little heap by itself. He then let out the cows, which ran to the dung and ate it with great relish. This repast, it seems, was regularly given to them once a day.
>
> "These cows were far from being in a starving condition, or driven by hunger to this strange diet. They were frolicsome, and their skins clean and glossy. They were not at all 'at the lifting,' as it is called in Scotland when the cattle of a small farmer are, from mere starvation, scarcely able to rise. They would have been reckoned in very fair condition for lean stock, not intended for the market, in any ordinary farm in the North of Scotland. The practice is general on the skirts of the Fjelde, about Roraas, and over all Bergens Amt.
>
> "If by a substitute like this the farmer can save a fourth part of hay that would otherwise be consumed, and can show a stock of cattle in such very fair condition for the month of February, the management may not be so laughable as it appears at first.
>
> "The inferior animals appear to be capable of forming acquired tastes as well as man. If the farmer can avail himself of these, whether produced at first by hunger or imitation, so as to spare other food, he is wise in doing so. He should not wait until the cattle are starving before giving them substitutes for hay or straw."

The bearing of this narrative upon what has been said of the value of dung is manifest. Since most of the waste nitrogen resulting from the consumption of food goes off in the urine anyway, it is evident that the twice digested constituents of the dung will be pretty thoroughly deprived of nitrogen; and since the horses observed by Mr. Laing got nothing but hay in the first place, the final cow-dung can hardly have been very rich, except in inorganic ingredients. It is an old adage that "when cattle eat straw they void straw." It is probable that the old custom above described may have prevailed formerly to a certain extent in many localities. Gasparin tells us that cow-keepers in the towns of Southern France habitually buy straw which has served for bedding horses and feed it to their cows, by whom it is eaten greedily, because of its saline taste. The practice has the sanction of high antiquity, to judge from Kipling's statement that the milch buffaloes kept in the great cities of India are habitually fed upon horse-manure. No matter how unpleasant these practices may seem to us, it will be admitted that they teach an instructive lesson as to the relations of food to dung.

Manure from Stall-fed Cattle.

On the other hand, there are certain districts in Europe, as will be explained more fully under the head of Farms, where cattle are kept less for the milk or flesh they yield than for the sake of the manure which is obtained from them. In the rich farming region about Dresden, in Saxony, for example, the land is kept up to the wheat-producing standard by means of stables of milch-cows. The cows are fed largely upon clover and distillery refuse from potatoes, — these crops being grown in rotation with wheat. The ultimate purpose of the manure is to enable the farmer to grow wheat which is sold off the farm as a money-bringing crop. Milk, or some dairy product, is sold also; but it is sold for what it will fetch, and is held to be a secondary consideration, the manure for the wheat being always of paramount importance.

Under these conditions, the farmer's aim is to obtain in the dung and urine of his animals the largest possible quantity of manure of the best possible quality. For him, the dictum that "the richer and the more abundant the food, the better the manure," has a very different meaning from what it had years ago for the Norwegian peasant.

So too in England, it has long been customary to buy fertilizing matters indirectly, i. e. in the form of concentrated fodders, of one kind or another, which are used at the farm to fatten cattle, whose manure is employed to enrich the farm. Even before the beginning of this century, Marshall noticed in the rich farming districts of the County Kent, that "Cattle are fed on oil-cake, without any other other view to profit than that of affording dung of a superior quality."

It is to be noted however, that in actual practice it does not follow that a ton of farmyard-manure obtained from richly fed animals will necessarily be stronger than a ton of manure from a stable where the animals are less richly fed, because the manure may be much more largely diluted with straw, or other litter, in the one case than in the other. In point of fact, many kinds of foods, rich in nitrogen, will cause an increased secretion of urine and will consequently lead to the use of more abundant supplies of bedding, so that, after all, a given weight of the manure may not contain any larger percentage of nitrogen than would be found in the same weight of manure, obtained at another stable from an inferior kind of food.

Fertilizing Value of Cattle Foods.

As a rule, the farmer both in buying and selling cattle food should take note of the value of the fertilizing matters which are contained in it. For example, there are found in one ton (2,000 lb.) of various foods, the following weights of fertilizing substances: —

	Potash. lb.	Phosp. Acid. lb.	Nitrogen. lb.	Estimated Value.[1] $
English hay	34	8	26	4.53
Red clover hay . . .	40	12	42	6.60
Dry corn stover . . .	34	8	10	2.93
Wheat straw	10	4	6	1.65
Oat grain	8	11	40	4.91
Indian corn	7	11	32	4.07
Cotton-seed-meal . .	44	59	140	18.39
Wheat bran	27	58	44	8.52
Malt sprouts	42	25	74	10.64
Mangolds	9	2	4	0.91
Turnips	6	2	3	0.67

Fertilizers carried off in Milk.

From a milk farm a considerable quantity of fertilizing matters will naturally be sent away in the milk; about half a pound of nitrogen, namely, nearly a quarter of a pound of pòtash, and one fifth of a pound of phosphoric acid in every hundred pounds of the liquid. Hence, in case a cow gives 2,000 quarts, or 4,300 lb. of milk in a year, and the milk be all sold as such, there would be carried away from the farm 22 lb. of nitrogen, 11 lb. of potash, and 9 lb. of phosphoric acid, to say nothing of the chemical composition of the calf which is produced every year. But since in order to get so large an amount of milk the cow must be richly fed, her manure will be doubly valuable, so that the real loss of fertility to the farm where milk is sold will be less than the foregoing figures would seem to indicate, and less, indeed, than would be the case on many farms where crops are sold directly.

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[1] In estimating the value of these fodders, the pound of potash (K_2O) is assumed to be worth $0.045, the pound of phosphoric acid (P_2O_5) $0.05, and the pound of nitrogen $0.10, which is much too low in certain cases, as in cotton-seed-meal, for example, in malt sprouts, and in bran. Perhaps 15 cents the pound for nitrogen would be a fairer estimate in these three instances. Still, the cost of handling the heavy dung diminishes the value of its constituents, as compared with those contained in concentrated commercial fertilizers. Moreover, the prices paid for artificial fertilizers are justified by the special uses to which they are put, viz. the forcing of crops which stand in need of one or another of them. But it would not be proper to allow so high a price for either of the constituents of farm-manure in case the manure is to be put upon soils or crops which have no particular need of them. The data which relate to the composition of the fodders are taken from the tables at the end of "How Crops Grow," — the first edition.

Old Views as to the Relations between Food and Manure.

It is an old rule that the dung and urine of cattle represent the plants upon which the cattle have fed minus those portions of the food which have been abstracted by the acts and processes of nutrition. But it is a rule which must not be taken too literally, in view of the great changes in chemical composition which the components of the plants undergo within the animals.

Young cattle, in growing, do of course subtract from the dung product whatever of phosphoric acid or of nitrogen is laid up within them to form bone, or flesh, or hide, or hair, or gristle. So too in respect to breeding animals, and to those which produce wool or milk. Moreover, it was thought, formerly, that a considerable portion of the nitrogen of the food of all animals is exhaled in the process of respiration, and so lost.

Boussingault found, for example, that some fresh horse-manure examined by him (dung and urine together) contained only 83 % of the nitrogen consumed in the food. In cow-manure he found 87 %. But in the light of existing knowledge it is evident enough that these samples of dung and urine must have been left to stand long enough to undergo some slight fermentation after they had left the animals before the analyses were begun. Numerous recent experiments have shown that, practically speaking, all the nitrogen eaten by adult animals in their food comes out from them again in the urine and dung, excepting what is stored up in wool, flesh, milk, or the like. Next to none of the nitrogen of the food leaves the animal in the gaseous form. Animals do not exhale either ammonia or free nitrogen, excepting of course the nitrogen of the air, which is breathed in as such and breathed out again. In this particular instance the loss of nitrogen was probably due to the evolution of ammonia. Schloesing, who has made elaborate experiments to test the question whether any free nitrogen gas is given off from dung, kept out of contact with air and undergoing that kind of fermentation which produces marsh-gas, could never detect a particle of free nitrogen. No other gases than carbonic acid, marsh-gas and hydrogen were evolved in two months time from the fermenting manure. He urges that all the nitrogen of the organic matters which are decomposed in this kind of fermentation is evolved as ammonia. He found in fact that some of the water of the moist manure was decomposed, its oxygen going to form carbonic acid, while the hydrogen united with the nitrogen in the manure to form ammonia.

It may sometimes happen, as Gibson and others have shown, that, in the presence of certain micro-organisms, free nitrogen may be liberated during processes of putrefaction, though in most cases it may be admitted, with Kellner, whose observations preceded those of Schloesing, that no nitrogen-gas is lost from moist organic matters which are slowly putrefying, unless, indeed, there should happen to be a nitrate in the mixture. If a nitrate be present, it will be deoxidized by the fermentation, and some of its nitrogen will escape as such, as will be explained in a subsequent chapter.

The Nitrogen in Manure is easily lost.

The ready loss of nitrogenous matters by fermentation of the dung and urine, which doubtless vitiated Boussingault's results, illustrates the important practical fact that much of the fertilizing matter in the food never gets back to the land. This point has been enforced anew by the experiments of Muntz and Girard, who kept animals of various kinds in stables provided with water-tight floors, and weighed and analyzed methodically, during considerable periods of time, the food, the litter, the manure, and the bodies of the animals. The differences between the quantities of nitrogen in the food, in the animals and animal products, and in the manure, showed that large losses of nitrogen do habitually occur. It was noticed that the fermentation, which sets in at once in the manure, as it lies under the feet of the animals, thanks to the micro-organisms which abound there, is almost wholly ammoniacal, and that appreciable quantities of ammonia may be formed in the course of a few hours, through the decomposition of the nitrogen compounds in the urine which, under favorable circumstances, may be almost wholly changed to ammonia.

In an experiment with horses, lasting from July 9 to August 10, 29 % of the nitrogen of the food could not be found again. In four experiments with cows, lasting from two to four weeks, there was a mean loss of almost 33 % of the nitrogen in the food consumed, though in one instance, where no litter was provided, the loss of nitrogen was as low as 27 %. In six experiments with sheep, the loss of nitrogen varied from 44 to 55 %, i. e., about one-half of the nitrogen of the food was lost. The excessive loss in this case was explained by the facts that the litter was left to lie under the animals during the entire experiment, it was not renewed from time to time as it had been in the other experiments, and that the concentrated sheep's urine is specially easily decomposed by way of fermentation. In this case, it appeared that more of the nitrogen originally contained in the food and the litter was lost than was recovered in the flesh, wool, and manure, and yet it is said that the conditions under which the experiments were made were more favorable for the preservation of manure than those ordinarily to be met with in actual farm practice. In one of the sheep experiments —

There was contained kilos of Nitrogen in the		There was found kilos of Nitrogen in the	
Food	94.867	Flesh produced . . .	8.185
Bedding . . .	3.075	Wool " . . .	2.720
		Manure " . . .	35.425
Sum	97.942		46.330

The loss of nitrogen was larger in case the animals got dry food than when their food was wet, and was naturally larger in hot, summer weather, than in the winter. In corresponding experiments upon manure kept in heaps, the loss of nitrogen was found to be very much less; being no more than 20 %, 10 %, and 5 %, for horses, cows, and sheep, respectively, instead of 29, 33, and nearly 50 %, as above.

Dungs differ as Animals do.

It hardly needs to be explained that what has been said above concerning the relation of the food to the value of the dung, applies more particularly to the case where the food and the dung of one and the same kind of animal are compared. Urine, of course, contains nothing but soluble matters (notably urea), which are the final result of transformations which the food undergoes within the animal body, and which are ultimately thrown off as effete and useless waste products; while dung, as has been said already, always consists largely of undigested matters, i. e., of those parts of the food which have not been dissolved and assimilated, but have passed through the alimentary canal without ever having got into the blood or become part and parcel of the animal. Hence the dung of cattle, which habitually eat coarse fodder, will necessarily differ very much from that of men and swine, which are supported by more concentrated kinds of foods. The manure of different kinds of animals will differ, withal, accordingly as they drink much or little water. Thus the peculiarly concentrated character of the manure of sheep and goats depends, in some measure, upon the fact that these animals drink but sparingly. A similar remark will apply to the dung of birds, also, which does, in fact, consist of a mixture of dung and urine.

It may be said, indeed, that each kind of manure has its own characteristics and peculiarities, in consonance with the fact that each kind of animal has its own way of utilizing and of rejecting food. There are, naturally enough, as wide differences between the excrements of dogs and cows as there are between the structure, kinds of food, and habits of life of the two animals.

In any event, the dung of flesh-eating animals, that of cats, for example, will manifestly be richer in nitrogen, and sometimes in phosphates also, than that of grazing animals. The same reasoning will apply to the mixed feeders, and it is true, in fact, that the excrements of men and swine and poultry are, in fertile regions, held to be more valuable than those of the grass-eating animals.

Manure of Swine.

It is noteworthy, by the way, that the French and German cultivators who are accustomed to pasture swine, or to feed them upon very thin wash of one kind or another, hold hog-manure in comparatively small esteem. It is only in England and in this country, where hogs habitually get grain or milk to eat, that their manure is thought to be worth much.

There are some experiments by Christiani which illustrate the value of the manure from fatting hogs. He compared it, as to its practical effect, with the manure produced by other kinds of stall-fed animals. Each of his experimental plots was heavily manured with the dung that had been allotted to it twice in a seven years' rotation of crops, which consisted of winter rape (manured), barley, wheat, oats, barley, wheat, and potatoes (manured). Reducing the crops harvested to terms of rye, it appears that there were produced in the seven years, from the hog-manure, 12,594 lb.; from the horse-manure, 12,190 lb.; from the sheep-manure, 11,485 lb.; and from the cow-manure, 10,887 lb.

It is a tenet of practical men that very little manure can be got from hogs, unless they are abundantly supplied with materials "to work upon," such as peat, leaves, weeds, sods, straw, or horse-manure; the fact being that animals, like hogs, men and poultry, which feed upon concentrated foods, do not void large quantities of indigestible matters, such as are observed in the dung of cows and horses. Hence, the bulk of the manure obtained from unlittered hogs is but small as compared with that obtained from animals kept on rough fodders. Moreover, the highly concentrated hog-manure is specially apt to be wasted by decay, unless materials are supplied to dilute and envelop it while it is yet fresh. It is none the less true, of course, that the hog-sty may readily be made a place for manufacturing a powerful compost, as will appear from what is said on compost-making in a subsequent chapter. In New England, manure from the hog-sty is highly esteemed, though it is seldom or never applied for cabbages, cauliflowers, or rutabagas, because an opinion prevails that these plants are specially apt to suffer from the disease known as clumpfoot, when hog-manure has been put upon the land.

Order of Merit of Dungs.

I am ignorant whether precise experiments have ever been made, from the chemical point of view, to test the comparative practical value of the excrements of different kinds of animals, fed, under like conditions, upon one and the same kind of food. It would not be very difficult, for example, to test this point by feeding separate parcels of cats and goats on bread or crackers, or by feeding hounds, sheep and hens on Indian meal. Some of the older agricultural experimenters may have attempted the thing without recourse to analysis; but, without the help of chemistry, they must have labored under great disadvantages.

Perhaps the classification of the French agriculturist Dombasle may have been founded on experiments in which the food of the animals was the same. Taking the dungs at their normal condition of dryness, he gives the order of "strength" for similar quantities of the several kinds as follows: goat, sheep, horse, hog, cow.

It would be the more interesting to determine, by experiment, the composition and quantity of dung from different animals similarly fed, because we are so much in the habit of contrasting the dung of animals that have been differently fed, that our conceptions upon this particular point are apt to be vague.

Horse-dung Contrasted with Cow-dung.

It is no wonder that the dung of the stall-fed horse is better than that of the grass-fed cow; but how is it when both are grass-fed? As has been said already, the dung of grazing horses is so far inferior to that of grain-fed horses that many people have esteemed it to be wellnigh worthless. But because it is wellnigh worthless as compared with stable-manure, it does not follow that it is inferior in any way to cow-manure produced under similar conditions. On the contrary, from what is known of the physiology of the horse, it might perhaps be argued, with some show of reason, that, with like rations, horse-dung would sometimes be better, chemically speaking, than cow-dung. It is an old remark that, "The dung of horses and mules is an admirable fertilizer, though care must be taken not to lay too much of it upon wheat land, because it produces an abundance of straw. Horse-dung, being of a very hot nature, is best for cold lands, and cow-dung for hot lands. When mixed together, they make a very good manure for most sorts of soils."

It is to be observed, moreover, on contrasting farmyard-manure, as obtained from cows or from horses, that the dissimilarity of the two kinds of manures seldom depends wholly upon differences as to food. It is in reality influenced by a variety of other conditions and circumstances. Horse-dung is apt to be drier of itself than the dung of neat cattle, and it is usually admixed with a comparatively large quantity of straw or other litter, and to these peculiarities, as much as to the character of the food, must be attributed the liability of horse-manure to "heat"—i. e., to be injured by untimely fermentations. To the dryness of horse-manure, again, and to the litter with which it is admixed, as much, perhaps, as to less emphatic digestive processes within the nobler animal, must be attributed the well-known fact that the seeds of weeds are more liable to be carried to the land in horse-manure than in the dung of cows. But this circumstance alone may serve, in some part, to explain the opinions of practical men as to the comparative value of the two kinds of manures.

One reason why the dung of pastured horses may do less good to the land than the dung of cows, is, that the droppings of the two animals may ferment in different ways upon the land. Possibly more nitrogen may go to waste during the decay of the loose dry droppings of the horses than will escape from the more compact flakes of cow-dung. In the words of Marshall, "The dung of horses, dropped on grass in summer, soon undergoes a change. Its substance is presently scooped out by insects; nothing but a porous bundle of undigested vegetable matter being left. If insects not only eat horse-dung, but fly away with it out of the field, it is in reality lost to that particular field." It was remarked, withal, long ago, by Sir Humphry Davy, that one reason why horses do not benefit pastures will be found in the fact, that, while they consume the grass by night, they drop a good part of their manure during the day-time, while they are at work upon the roads. The remark was made, it should be remembered, at a time when all transportation in England was by means of wagons on roads or by boats on canals.

Amount of Manure produced by Animals.

From the experiments of Boussingault, upon a rather small farm-horse, and those of Hofmeister, it appears (as Heiden has set forth) that the fresh excrements of a horse fed on hay and oats amount to rather more than 30 lb. a day, and contain some 6 or 8 lb. of dry matter. According as the animal is or is not bedded with 6 lb. of straw, there will be contained in the manure of a single day, 0.2 and 0.22 lb. of nitrogen, and 1 lb. and 1.4 lb. of ash-ingredients. Very similar figures have been obtained in experiments with cows. Thus, Boussingault fed a cow on potatoes and rowen, and got per diem 73½ lb. of moist excrements that contained nearly 10 lb. of dry matter. According as she was not bedded at all, or with 6 and 10 lb. of straw respectively, it appeared that the manure contained 0.26, 0.28, and 0.29 lb. of nitrogen, and 1.73, 2.05, and 2.28 lb. of ash-ingredients.

Henneberg and Stohmann's oxen, that were merely "maintained" at rest, gave for every 1,000 lb. of live weight 64½ lb. of moist excrement that contained a little more than 8 lb. of dry matter. The manure contained 0.22, 0.23, and 0.25 lb. of nitrogen, and 1.3, 1.6, and 1.8 lb. of ashes, according as the animals received no bedding, or 6 and 10 lb. of straw. Fatting oxen gave, per 1,000 lb. live weight, 82 lb. of moist excrement (or 9 lb. dry), and the manure contained 0.36, 0.38, and 0.39 lb. nitrogen, and 1.8, 2.1, and 2.4 lb. of ash-ingredients, according as there was no litter, or 6 or 10 lb. of it.

Boussingault concluded, from his own experiments, that a cow may produce in a year some 22,000 lb. of solid and 6,800 lb. of liquid excrement; while the yearly production of a horse may be rated at 13,000 lb. of solid and 2,600 lb. of liquid. Wolff, in his turn, collected during 2½ days in April all the manure that was produced by a stable that contained 46 cows, 20 heifers, and 14 calves. The animals were fed chiefly on hay and beets. They received 11,810 German lb. of fodder and bedding during the period in question, and produced 14,550 lb. of manure which contained 4,030 lb. of dry matter. A small portion of the fresh manure was taken for analysis, and the rest of it (14,330 lb. of fresh = 3,975 lb. of dry manure) was left out of doors for a year in a heap 3 or 4 feet high. At the end of the year, the heap was no more than about one foot high, and its contents weighed 6,730 lb. when moist, and 1,360 lb. when dry. The following percentage of matters was contained in each of the two kinds of manure: —

	Dry fresh Manure.		Dry rotted Manure.	
Soluble organic matters	9.7	14.4	7.0	12.0
" mineral matters	4.7		5.0	
Insoluble organic matters	76.3	85.6	56.3	88.0
" mineral matters	9.3		31.7	
Nitrogen in soluble organic matters	0.63	1.65	0.3	2.1
" " insoluble organic matters	0.86		1.7	
" " NH_3 compounds	0.16		0.1	

No nitrates could be detected, either in the fresh or the rotted manure. The loss of soluble nitrogen, as the dung decays, depends in part on the leaching action of rain, in part on volatilization of ammonia, and in part on the formation of inert humus-like compounds.

Heiden determined how much dung and urine were voided per head and per 1,000 lb. of live weight, in winter and in summer, by a stable of 30 head of cattle, as follows: —

	Lb. Fresh Manure.			Lb. Dry Substance.		
	Dung.	Urine.	Total.	Dung.	Urine.	Total.
Winter	95	9	104	19	0.42	19.42
Summer	88	17	105	17	0.57	17.57
Very salt food	82	36	118	17	0.88	17.88

When the food of the animals was very salt, as in the last line of the table, more water was drunk and more urine voided, but there was no increase in the amount of dry manure. Throughout the experiments, the food was abundant and varied. In winter it was dry for the most part, but in summer much of it was green.

The waste of this manure, as it lay in carefully kept dung-heaps and urine cisterns, was as follows: —

Loss of Original Materials in the Course of	From the Manure from Winter Food.		From the Manure from Summer Food.	
	Fresh Manure. %	Dry Matter. %	Fresh Manure. %	Dry Matter. %
6 weeks	6.36	16.76	8.03	27.37
9 "	12.80	23.03	15.11	33.19
12 "	18.28	25.42	19.18	35.46
15 "	17.80	26.21	20.40	35.92

It was found, in subsequent experiments, that this waste could be lessened very considerably by the use of gypsum and kainit (which see). In another trial, where the dung was not firmly packed, but merely thrown into loose heaps from hand-barrows, the loss of moist manure in 15½ weeks was 25 %, and the loss of dry substance 35 %.

Analyses of Manures.

The following tables contain the essential points of several other analyses of manures, as determined by different observers: —

DUNG ALONE OF NEAT CATTLE.

Distinguishing Number of the Specimen.	Water. H_2O	Dry Matter. . .	Ash. . .	Potash. K_2O	Lime. CaO	Magnesia. MgO	Total Phosphoric Acid. P_2O_5	Soluble Phosphoric Acid. . .	Ammonia. NH_3	Total Nitrogen. N
1 . . .	86.00	14.00	1.69	....	....	....	0.10	....	....	0.32
2 . . .	84.00	16.00	2.40	0.10	0.40		0.23	....	....	0.30
3 . . .	82.30	17.70	2.17	0.27	0.77	0.15	0.14	....	....	0.20
4 . . .	76.19	23.81	3.09	0.60	0.58	0.03	0.52	....	....	0.79
5 . . .	82.05	17.95	3.03	0.05	....	....	0.16	....	....	0.44
6 . . .	46.57	53.43	6.91	0.04	....	....	0.12	....	....	0.44
7 . . .	80.35	19.65	....	0.25	....	....	0.15	....	....	0.36
8 . . .	83.00	17.00	....	0.14	....	....	0.24	....	....	0.33
9 . . .	79.70	20.30	....	0.23	....	....	0.16	....	....	0.34
10 . . .	....	....	....	0.15	....	....	0.19	....	....	0.31
11 . . .	....	....	....	0.44	....	....	....	....	....	.....

1. Pure cow-dung, from a milch cow which consumed per diem 16.5 lb. of rowen, 35.2 lb. of potatoes, and 132 lb. of water; and produced in the same time 62.5 lb. of dung and 18 lb. of urine, and altogether 80.5 lb. of solid and liquid excrement. Meanwhile 72.5 lb. of water and 9.3 lb. of the dry food were given off in the form of gas from the lungs and skin of the animal. (Boussingault, Mémoires de Chimie Agricole, pp. 1–13.) It may be remarked that in other instances B. obtained different results, as to the amounts of solid excrement voided. Thus while cows of 1200 lb. live weight, that were fed on 34.6 lb. of rowen per head and per day, voided 52.8 lb. of solid excrement, they yielded no

more than 16.87 lb. of solid excrement per day during a fortnight when they ate nothing but 134 lb. of beets each day; when fed upon nothing but 84 lb. of potatoes per diem each of them voided 28.6 lb. of solid excrement.

2. Dung of cows, winter food. (Stoeckhardt, in his Chemische Feldpredigten, 1856, p. 84.)

3. Fresh dung free from urine and litter, of steers fed with 24 lb. of lucern per head and day. (Analysis made at the Colorado Exp. Station, cited in Conn. Report for 1889, p. 118.)

4. Fresh cow-dung without litter, but may have been wet with urine. Winter food. (R. F. Kedzie, in laboratory of the Bussey Institution.)

5. Solid excrement from 4 cows, collected at Montpellier, France, in early morning, April 17, when the animals were fed on maize ensilage and small quantities of lucern hay, straw and turnips, and slight additions of bran and cotton-seed-meal. (Audoynaud and Zacharewicz, Biedermann's Centralblatt, **15**, 517.)

6. Similar to 5, but collected on May 22, when the animals were fed on mown annual clover (T. incarnatum) together with a little straw, bran and cotton-seed-meal.

7. Dung alone from a Normandy cow of about 1200 lb. live weight. When fed upon 20 lb. of lucern hay, 88 lb. of beets mixed with chaff and 44 lb. of water per diem, there was produced 59 lb. of dung and 23 lb. of urine, or together 82 lb. of solid and liquid excrement. (Muntz & Girard, Les Engrais, **1**, 192.)

8. Dung alone from cow No. 7, when fed with 154 lb. of beets. The cow drank no water. There was produced each day on the average 42 lb. of dung and 88 lb. of urine, or together 130 lb. of solid and liquid excrement. (Muntz and Girard, *loc. cit.*)

9. Dung alone from cow No. 7, when fed with 26.4 lb. of lucern hay and 66 lb. of water. There was produced 48.4 lb. of dung and 13.6 lb. of urine, or together 62 lb. of solid and liquid excrement. (Muntz & Girard, *loc. cit.*)

10. Dung alone from cows fed with 118 lb. fresh-cut lucern and 108 lb. of water. Each animal produced 73 lb. of dung and 40 lb. of urine, or together 113 lb. of solid and liquid excrement. (Muntz & Girard, *loc. cit.*)

11. Mean of several samples of cow's dung. (Muntz & Girard.)

Manure of Neat Cattle, *i. e.*, Mixtures of Dung, Urine, and Litter, or of Dung and Urine.

Distinguishing Number of the Specimen.	Water.	Dry Matter.	Ash.	Potash.	Lime.	Magnesia.	Total Phosphoric Acid.	Soluble Phosphoric Acid.	Ammonia.	Total Nitrogen.
	H_2O	. .	. .	K_2O	CaO	MgO	P_2O_5	. .	NH_3	N
50 . . .	85.30	14.70	2.04	0.36	0.29	0.19	0.16	....	0.26	0.53
51 . . .	84.30	15.70	....	....	....	....	....	....	....	0.41
52 . . .	71.69	28.31	10.08	0.48	0.17	0.13	0.30	....	0.13	0.43
53 . . .	82.42	17.60	2.27	0.30	0.28	0.12	0.20	....	0.10	0.42
54 . . .	81.80	18.20	1.80	0.35	....	....	0.13	....	....	0.34
55 . . .	72.87	27.13	6.70	1.69	0.41		0.20	....	....	0.79
56 . . .	75.00	25.00	6.22	0.39	0.24	0.18	0.14	....	0.27	0.46
57 . . .	77.71	22.30	4.71	0.46	0.37	0.11	0.13	....	0.16	0.54
58 . . .	74.02	25.98	3.94	0.56	0.58	0.13	....	....	....	0.41
59 . . .	....	....	....	0.29	0.16	....	0.14	....	0.04	0.34
60 . . .	....	....	....	0.29	0.16	....	0.14	....	0.01	0.27
61 . . .	....	....	....	0.25	0.08	....	0.21	....	0.20	0.47
62 . . .	....	....	....	0.28	0.09	....	0.21	....	0.13	0.42

MANURE OF NEAT CATTLE. — *Continued.*

Distinguishing Number of the Specimen.	Water. H_2O	Dry Matter. . .	Ash. . .	Potash. K_2O	Lime. CaO	Magnesia. MgO	Total Phosphoric Acid. P_2O_5	Soluble Phosphoric Acid. . .	Ammonia. NH_3	Total Nitrogen. N
63 . . .	80.31	....	....	0.42	....	....	0.32	0.10	....	1.30
	71.51	....	....	0.63	....	....	1.20	0.53	....	1.39
	74.55	....	....	0.41	....	....	0.44	0.11	....	0.71
	74.75	....	....	0.25	....	....	0.32	0.11	....	0.57
	83.92	....	....	0.33	....	....	1.40	0.17	....	1.21
	79.86	....	....	0.40	....	....	0.52	0.12	....	0.88
	79.50	....	....	0.34	....	....	0.98	0.12	....	1.00
	82.51	....	....	0.27	....	....	0.36	0.15	....	0.29
64 . . .	75.93	24.07	4.34	0.47	0.31	0.01	0.56	....	0.13	0.67
65 . . .	69.52	30.48	3.18	0.41	....	....	0.35	....	0.14	0.65
	78.70	20.31	2.99	0.50	....	....	0.28	....	0.14	0.53
	55.31	44.69	10.12	0.82	....	....	0.54	....	0.10	0.96
	64.85	35.15	7.30	0.61	....	....	0.36	....	....	0.60
	70.51	29.49	7.60	0.46	....	....	0.39	....	....	0.72
	71.95	28.05	5.55	0.93	....	....	0.46	....	....	0.51
	....	....	....	0.39	....	....	0.21	....	....	0.55
	....	....	....	0.74	....	....	0.34	....	....	0.61
	....	....	....	0.26	....	....	0.23	....	....	0.37
Mean of No. 65	68.47	31.53	6.12	0.57	....	....	0.35	....	....	0.61
66 . . .	80.70	19.30	....	0.54	0.52	0.17	0.17	....	....	0.40
	77.00	23.00	....	....	....	....	....	....	....	....
	80.80	19.20	....	0.46	0.20	0.11	0.14	....	0.02	0.30
	78.88	21.12	....	0.55	0.20	0.11	0.14	....	0.03	0.34
67 . . .	73.44	26.56	....	0.50	0.44	0.21	0.32	....	0.06	0.47
	73.29	26.71	....	0.49	0.35	0.19	0.29	....	0.06	0.49
68 . . .	73.00	27.00	....	0.87	....	....	0.36	....	....	0.64
69 . . .	71.63	28.37	....	0.89	....	....	0.13	....	....	0.60
	73.50	26.50	....	0.94	....	....	0.24	....	....	0.71
	72.86	27.14	....	0.81	....	....	0.29	....	....	0.73
	72.00	28.00	....	....	....	....	....	....	....	0.62
70 . . .	83.78	16.22	4.28	0.43	....	....	0.26	....	0.13	0.46
71 . . .	81.42	18.58	4.89	0.74	....	....	0.27	....	0.11	0.46
72 . . .	76.54	23.46	4.04	0.79	....	....	0.31	....	0.19	0.67
73 . . .	75.87	21.13	4.46	0.71	....	....	0.33	....	0.26	0.59
74 . . .	81.50	18.50	2.50	0.47	....	....	0.14	....	0.03	0.32
75 . . .	77.20	22.80	2.70	0.57	....	....	0.14	....	0.07	0.41
76 . . .	62.70	....	....	1.08	....	....	0.31	....	....	0.65
77 . . .	56.50	....	....	0.93	....	....	0.38	....	....	0.65
78 . . .	71.30	....	....	0.85	....	....	0.28	....	....	0.65
79 . . .	79.40	....	....	0.76	....	....	0.18	....	....	0.41
80 . . .	75.10	....	....	0.76	....	....	0.15	....	....	0.51
81 . . .	77.50	22.50	2.20	0.40	0.31	0.11	0.16	....	....	0.34
82 . . .	77.73	....	....	0.53	....	....	0.17	....	....	0.50
83 . . .	75.25	....	....	0.44	....	....	0.29	....	....	0.43

50. Cow-manure free from litter, from cows fed on as much hay as they would eat, with additions of 4 quarts of wheat-bran and 4 quarts of mangolds per head and day. A cubic foot of this manure weighed 63 lb. (S. W. Johnson, Report Conn. Exp. Station, 1889, p. 118.)

51. Mixed dung and urine of cows, free from litter. (Payen & Boussingault, Ann. Ch. et Phys., 1841 (3.), **3**. 103.)

52. Manure from milch cows fed liberally upon corn-meal, bran, timothy hay and roots. (S. W. Johnson, Report Conn. Exp. Station, 1889, pp. 117, 118.)

53. Manure from milch cows fed on hay and stover. It was kept closely packed, in a manure-house which had a cement floor. (S. W. Johnson, Conn. Agric. Exp. Report, 1890, 71.)

54. Fresh manure of cows fed with rowen and potatoes and bedded with 6.5 lb. of straw. (Boussingault, cited by Muntz & Girard, **1**, 240.)

55. Four-weeks-old manure from a stable where the cows were fed with a mixture made of 100 lb. green-cut clover and 5 lb. of rye-straw. (R. Hoffmann.)

56. Cow-manure. (Bretschneider.)

57 and **58**. Taken in February from the centre of dung-heaps at two different cow-stables in Germany. (Schmid.)

59. Manure from 9 cows fed upon hay, crushed grain, cabbages, beets, and brewers' grains. When bedded with 3.5 kilo of peat-moss per head and day. (Fleischer, Biedermann's Centralblatt, 1887, **16**. 810.)

60. Animals same as in No. 59, but bedded with 4.6 kilos. of rye-straw.

61. Manure from 10 cows fed upon hay, grain, kohlrabi, potatoes and brewers' grains. When bedded with 3.5 kilo peat-moss.

62. Same animals as in No. 61, but bedded with 4.3 kilos. of rye-straw. (Fleischer.)

63. Eight samples of manure from neat cattle. (Strohmer, Bied. Cent.-Blatt, 1889, p. 643.)

64. Manure of oxen fatting on distillery slop from beet-roots and oil-cake. Sample taken from a heap of 70 cubic metres. (Petermann.)

65. Nine samples of manure of neat cattle that were bedded with peat-moss. (Petermann, Biedermann's Centralblatt, 1888, **17**. 451.)

66. Samples of fresh manure (one week old) of milch cows. (Holdefleiss, Hoffmann's Jahresbericht, 1891, **14**. p. 105.)

67. Samples of fresh manure (one week old) of stall-fed oxen. (Holdefleiss, *loc. cit.*)

68. Manure of stall-fed oxen, kept in deep stalls. (Holdefleiss, *loc. cit.*)

69. Manure which had been suffered to lie, together with much straw, under the animals during 2 and 3.5 months. 70 cows and draught oxen were kept in the stable, and their manure was found to be in a good mellow condition at the times above stated. Holdefleiss remarks on the unusually good quality of the manure, in spite of the fact that much more straw had been used in the preparation of it than is used in the making of ordinary farmyard manure. The great excess of straw in these samples, and some others, explains the high percentage of potash, as stated in the table. (Holdefleiss, Biedermann's Centralblatt, 1884, p. 88; and **10**. 587, 588.)

70 and **71**. Manure taken from heaps at two Flemish farms where the manure was thrown out every day from the cow-stalls. (Biernatzki, Hoffmann's Jahresbericht, 1881, p. 248.)

72 and **73**. Manure from two other Flemish farms carried on like Nos. 70 and 71, only that the cow-stalls were provided with movable cribs, and the dung and litter were left to accumulate under the animals. (Biernatzki, *loc. cit.*)

74. Cow-manure taken from a dung-heap. (Emmerling, Hoffmann's Jahresbericht, 1882, p. 333.)

75. Cow-manure taken from a deep stall. (Emmerling, *loc. cit.*)

76 to **80**. Manure from a stable of 8 cows bedded with from 12 to 13 lb. of straw per head and day. (Muntz & Girard, Les Engrais, **1**. 241.) For No. 76 the cows were fed on lucern hay, beets and rye-meal; for No. 77 they got green-cut lucern, and rye-meal; for No. 78 they had green-cut lucern and barley-meal; for No. 79 they had cabbage-leaves, meal and straw, and for No. 80 they were at pasture and got some barley-meal in addition.

81. Average composition of fresh cow-manure, with litter, as computed by Wolff.

82. Fresh manure of calves, richly fed in pens and bedded liberally with finely cut wheat-straw. (G. C. Watson, U. S. Exp. Station Record, **5.** 388.)

83. Fresh manure of cows, richly fed and bedded liberally with cut wheat-straw. (Watson, *loc. cit.*)

MIXED FARM-MANURE.

Distinguishing Number of the Specimen.	Water. H_2O	Dry Matter. . .	Ash. . .	Potash. K_2O	Lime. CaO	Magnesia. MgO	Total Phosphoric Acid. PO_5	Soluble Phosphoric Acid. . .	Ammonia. NH_3	Total Nitrogen. N
150 . . .	70.00	30.00	2.77	0.53	....	....	0.25	....	....	0.77
151 . . .	79.62	20.38	6.56	0.51	0.56	0.24	0.20	....	....	0.41
152 . .	58.64	41.36	21.19	0.40	....	....	0.22	....	....	0.41
	66.25	33.75	18.51	0.60	....	....	0.62	....	....	0.46
	82.43	17.57	6.38	0.27	....	....	0.29	....	....	0.49
	68.91	31.09	9.41	0.51	....	....	0.31	....	....	0.49
	80.20	19.80	12.56	0.10	....	....	0.17	....	....	0.19
	74.41	25.59	14.20	0.23	....	....	0.43	....	....	0.34
	83.02	16.98	5.51	0.23	....	....	0.09	....	....	0.32
	66.01	33.99	20.82	0.22	....	....	0.33	....	....	0.36
153 . . .	54.70	45.30	34.43	0.16	0.47	0.50	0.72	....	0.01	0.46
154 . . .	71.00	29.00	4.40	0.52	0.57	0.14	0.21	....	....	0.45
155 . . .	75.00	25.00	5.80	0.63	0.70	0.18	0.26	....	....	0.50
156 . . .	79.00	21.00	6.50	0.50	0.88	0.18	0.30	....	....	0.58
157 . . .	66.17	33.83	5.59	0.67	1.19	0.15	0.31	....	0.12	0.64
158 . . .	69.83	31.17	....	1.22	1.34	0.05	0.32	0.14	0.08	0.74
159 . . .	67.32	32.68	....	0.88	1.92	0.08	0.45	0.15	0.76	0.75
160 . . .	80.02	19.98	....	0.42	1.97	0.09	0.27	0.09	0.06	0.54
161 . . .	75.42	24.58	....	0.49	1.78	0.14	0.45	0.18	0.10	0.61
162 . . .	73.90	26.10	....	1.08	2.27	0.04	0.12	0.06	0.07	0.21
163 . . .	72.33	27.67	5.87	0.69	0.85	0.14	0.30	....	0.02	0.46
164 . . .	77.08	22.92	7.42	0.71	0.34	0.15	0.34	....	0.16	0.53
165 . . .	79.95	20.05	....	0.84	....	....	0.40	....	....	0.78
166 . . .	75.57	24.43	....	0.70	....	....	0.29	....	....	0.68
167 . .	78.02	21.98	9.38	0.60	....	....	0.27	....	....	0.48
	78.69	21.31	8.57	0.60	....	....	0.29	....	....	0.47
	76.43	22.57	9.80	0.69	....	....	0.36	....	....	0.53
	78.25	21.75	8.70	0.64	....	....	0.36	....	....	0.48
168 . .	70.07	29.93	9.26	0.81	....	....	0.43	....	....	0.66
	71.30	28.70	8.24	0.81	....	....	0.43	....	....	0.64
	70.22	29.78	8.18	0.87	....	....	0.46	....	....	0.66
	69.90	30.10	8.53	0.85	....	....	0.46	....	....	0.66
169 . .	67.25	32.55	5.47	0.58	....	....	0.31	....	....	0.50
	73.73	26.27	3.51	0.49	....	....	0.24	....	....	0.37
170 . . .	73.27	26.73	3.57	0.51	....	....	0.29	....	....	0.34
171 . . .	77.85	22.15	6.68	0.57	0.60	0.14	0.35	....	....	0.58

150. Ideal composition of fresh, undecomposed manure — from a 400-acre English farm devoted to the four-course rotation — as calculated from the average composition of the matters which are supposed to enter into the manure, viz. roots, hay, straw, some oil-cake, and grain. (Lawes, Journal of the Royal Agricultural Society of England, 1862, **23.** 46.)

151. Mean of several analyses of different samples of half-rotted farmyard-manure from a stable of 30 neat cattle and 30 horses, and from 12 to 20 hogs. The manure was decidedly moist, the straw in it was not completely decomposed, though it was soft and filamentous. (Boussingault, Ann. Ch. et Phys. (3.) **1.** 234. and **3.** 100.)

152. Cubic-foot samples of farm-manure sent by eight different Scotch farmers to Professor Anderson of Glasgow and analyzed by him according to a uniform plan. The differences in composition of these manures were thought to depend chiefly upon the varying amounts of litter used at the farms. The proportion of sand in these eight samples varied from 22 % to upward of 55 % of the dry matter of the manures. (Highland and Agric. Soc. of Scotland, 1872, (4.) 4. 320.)

153. Well rotted barnyard-manure from young neat cattle fed with hay. The manure contained 25% of clay from the yard. This manure weighed 40 lb. to the cubic foot. (S. W. Johnson.)

154. Average composition of fresh farm-manure. (Wolff.)

155. Average composition of moderately rotted farm-manure. (Wolff.)

156. Average composition of very thoroughly rotted farm-manure. (Wolff.)

157. Fresh long manure, consisting of a mixture of horse, cow, and pig-dung and urine, and the straw that had served the animals as litter. It had lain in the dung-pit 14 days (in October), at a time when no rain had fallen. (Voelcker, Royal Agric. Soc. Journal, 1856, xvii, 194.)

158. Farm-manure taken in February from a heap (in a yard) that was 3.5 months old. (Voelcker, *loc. cit.*)

159. Farm-manure from a heap 3.5 months old, which had lain under cover from November to February. (Voelcker, *loc. cit.*)

160. Farm-manure which had lain spread out during the six months, November to May. (Voelcker, *loc. cit.*)

161. Well rotted farm-manure, 6 months old. (Voelcker, *loc. cit.*)

162. Well rotted farm-manure, 8 months old. (Voelcker.)

163. "Box manure," consisting of the mixed manure of bullocks, horses and pigs. By means of a fine sieve, 58.3% of dung were separated from 41.7% of straw. (Way, Journal of Royal Agric. Soc. of England, 1850, 2. 769.)

164. Taken from the accumulations of a barn that contained only young growing animals and a few horses. The food was good timothy hay, liberal quantities of bran, a few oats, and a little corn-meal. (S. W. Johnson, Report Conn. Exp. Station, 1889, pp. 117, 118.)

165. Mixed manure of cows and horses, taken from a compact bed two feet thick, which had accumulated during the winter in a large covered yard, and had been trampled upon by the animals. It was estimated that 80 tons of straw had been used for bedding 45 animals 195 days, and that 466 tons of manure were produced. (Roberts, 3d N. Y. Cornell Report.)

166. Similar to No. 165, but produced during another year, when less cotton-seed-meal was fed. In this case, 24 cows, 1 bull, 12 horses, 1 colt, 7 winter calves, and 12 spring calves, regarded as 47 adult animals, produced 199.5 tons of manure in 5 months. (Roberts, *loc. cit.*)

167 to 170. Manure obtained in summer from a herd of about 25 cows and a few steers and sheep, 12 calves and ten horses, littered with as little straw and sawdust as was consistent with cleanliness. The manure was hauled out by alternate loads and thrown into two heaps; one (No. 167) in an open yard, exposed to sun and rain, but on a place so dished and puddled with clay that no noticeable portion of the leachings could escape; while the other heap (No. 168) was kept under a shed open on one side and wholly above ground. The cattle and a few pigs were allowed to run over the heaps for an hour or two each day to ensure a certain amount of compaction as the heaps were formed. When the manure was hauled out in August, 29 loads of nearly 3,000 lb. each were found in the exposed heap, and 34 loads of slightly less than 2,000 lb. each, were got from the covered heap. In a repetition of the foregoing trial, made in the autumn and early winter, 56 loads of 2,800 lb. each were hauled from the open yard (No. 169) early in February and 54 loads of 2,500 lb. each were hauled from the covered heap (No. 170). It appeared that in summer more organic matter and more nitrogen were lost from the exposed heap than from the covered heap, while in winter the reverse of this seemed to be true. That is to say, the manure lost relatively most from overheating under the covered shed in winter, and when exposed to the sun in the summer. (Frear, Armsby & Hunt, Penn. Report, 1892, ii., 79.)

171. Manure from 32 horses, 3 cows and 12 hogs. The figures cited are the means of 4 analyses, made in 4 successive years. (Lecouteux, Biedermann's Centralblatt, 1881, **10.** 177.)

HORSE-MANURE.

Distinguishing Number of the Specimen.	Water. H_2O	Dry Matter. . .	Ash. . .	Potash. K_2O	Lime. CaO	Magnesia. MgO	Total Phosphoric Acid. P_2O_5	Soluble Phosphoric Acid. . .	Ammonia. NH_3	Total Nitrogen. N
200 . . .	75.30	24.70	....	....	....	....	0.30	....	....	0.55
201 . . .	75.40	24.60	....	....	....	....	0.17	....	....	0.74
202 . . .	76.00	24.00	3.00	0.30	0.30		0.35	....	....	0.50
203 . . .	67.40	32.65	3.35	0.72[1]	....	....	0.23	....	....	0.67
204 . . .	75.76	24.24	5.07	0.51	0.30	0.19	0.41	....	0.26	0.53
205 . . .	69.30	30.70	5.06	0.63	0.74	0.29	0.67	....	0.12	0.69
206 . . .	70.79	....	....	0.53	....	....	0.21	....	....	0.51
207 . . .	67.28	32.72	6.49	0.22	0.17	0.20	0.35	....	0.15	0.47
208 . . .	72.13	27.87	3.37	0.59	0.41	0.17	0.12	....	0.44	0.67
209 . . .	72.35	27.65	2.50	0.15	....	....	0.40	....	....	0.57
210 . . .	70.00	30.00	....	0.54	....	....	0.49	....	....	0.72
211 . . .	....	....	....	....	....	....	....	....	....	0.5 to 1.5
212 . . .	....	....	....	....	....	....	....	....	....	0.2 to 0.3
213 . . .	....	....	....	....	....	....	....	....	....	0.30
214 . . .	64.90	35.10	....	0.84	....	....	0.32	....	....	0.48
215 . . .	65. to 80.	20. to 35.	....	0.27 to 1.01	....	....	0.17 to 0.35	....	....	0.48 to 0.67
216 . . .	69.80	30.20	....	0.80	....	....	0.37	....	....	0.47
217 . . .	57.30	42.70	....	0.56	....	....	0.29	....	....	0.44
218 . . .	54.16	45.86	....	0.49	....	....	0.35	....	....	0.44
219 . . .	....	....	....	0.48	....	....	0.26	....	....	0.49
220 . . .	70.90	29.10	3.60	....	....	....	0.35	...	....	0.56
221 . .	73.78	26.22	3.77	0.55	....	....	0.42	....	0.39	0.79
	73.11	26.89	3.69	0.46	....	....	0.33	...	0.42	0.93
222 . . .	60.58	39.42	....	....	....	....	....	....	....	0.80
223 . . .	71.30	28.70	3.30	0.53	0.21	0.14	0.28	....	....	0.58

[1] K_2O and Na_2O.

200. Horse-dung, by itself. (Payen & Boussingault, Ann. Ch. et Phys. (3.) **3.** 103.)

201. Mixed dung and urine of a horse. (Payen & Boussingault, *loc. cit.*)

202. Fresh horse-dung, winter food. (Stoeckhardt, Chemische Feldpredigten, 1856, 84.)

203. Fresh manure of horses fed with hay and oats, and bedded with 4.5 lb. of straw per head and day. (Boussingault, cited by Muntz and Girard, in "Les Engrais," **1.** 240.)

204. Fresh horse-manure from stables of street-railway companies in New York City. The horses were fed with oats, corn-meal and chopped hay, in nearly equal proportions. The manure contained no long straw, and weighed 4,535 lb. to the cord, or about 35 lb. to the cubic foot. (S. W. Johnson, Conn. Agric. Rep., 1873, p. 348.)

205. Horse-manure taken from a carload brought from New York City. (S. W. Johnson, Rep. Conn. Agric. Exp. Station, 1880, p. 43.)

206. Horse-manure from animals fed liberally on hay and oats. The sample contained 30 lb. of straw bedding, and 466 lb. of mixed dung and urine. (N. Y. Cornell Station.)

207. Fresh horse-dung from an animal fed daily on 14 lb. of timothy hay and 4 quarts of oats mixed with cracked maize. The dung was collected in dry winter weather, a few hours after it had been dropped. A sample of the fresh dung contained 73.86% of water. (R. F. Kedzie, in Laboratory of the Bussey Institution.)

208. Horse-manure. (Bretschneider.)

209. Solid excrements of two horses, collected 21 May at Montpellier, France. The food consisted of lucern hay and oats. (Audoynaud and Zacharewicz, Biedermann's Centralblatt, **15.** 518.)

210. Dung of a farm-horse fed with 17.6 lb. of a mixture of maize and oats, 6.6 lb. of hay and straw, and 22 lb. of water, and producing 20.6 lb. of dung, and nearly 3 lb. of urine per day. (Muntz & Girard, "Les Engrais," **1.** 196.)

211. Dung of horses fed with nothing but oats or maize, or horse-beans, and yielding 4.5 to 11 lb. of solid excrement per day. (Muntz & Girard, *loc. cit.*, p. 197.)

212. Dung of horses fed with nothing but hay, and producing from 18 to 40 lb. of solid excrement per day. (Muntz & Girard.)

213. Dung of horses fed with ordinary rations of hay or straw and grain, and producing from 11 to 33 lb. of solid excrement per day. (Muntz & Girard.)

214. Manure from omnibus horses in Paris. (Muntz & Girard, "Les Engrais," **4.** 242.)

215. Fresh manure as sold to farmers from the yards of the Omnibus Co. of Paris, France. (Muntz & Girard, "Les Engrais," **1.** 356.)

216. Manure from the same stables as No. 215, after it had been left by a farmer in a heap in the open air for 6 months. (Muntz & Girard, *loc. cit.*, **1.** 359.)

217. Fresh horse-manure taken from large heaps at a cavalry camp, at Saint Maur, France. (Muntz & Girard, *loc. cit.*)

218. Same manure as No. 217, after it had been left to rot in the heaps during 2 months. (Muntz & Girard, *loc. cit.*, **1.** 361.)

219. Fresh manure of horses fed on hay and grain, and bedded with finely cut wheat-straw. (G. C. Watson, U. S. Exp. Station Record, **5.** 389.)

220. Horse-manure from a stable in which German peat-fibre had been used as litter. (Voelcker, Roy. Ag. Jour. (2.), **19.** 246.)

221. Air-dried manure of horses that had been bedded with fine peat-moss. A five-inch layer of the peat was placed in the stalls and left there. At the end of three weeks it had become moist, and the first sample was taken for analysis. More peat was then strewn upon that already in the stalls, and at the end of the month, the second sample of the manure was collected for analysis. (Arnold, Biedermann's Centralblatt, 1881, **10.** 590.)

222. Manure from inns in Southern France, consisting of the excrements of horses and mules that were fed upon hay and oats, and employed by carters for hauling goods upon the roads. The animals were bedded with straw, "not in excess." The sample analyzed was taken from a heap of manure one month old after fermentation had begun. The heap had been wet but little, and the dryness of the manure, and its consequent "strength" are noticeable. This specimen was reckoned to be a fair sample of horse-manure as produced in tavern stables at that date on the highways of Southern France. When taken from the heap, this manure weighed 660 kilos. per cubic metre, and it weighed 820 kilos the cubic meter, when firmly trodden in a cart. (Boussingault, Payen and Gasparin, Ann. Ch. et Phys., 1842 (3.), **6.** 457; and Gasparin's Cours d'Agriculture, **1.** 593, 596, 599, 600, 642.) From the result of this analysis, and of others made by Boussingault, Gasparin was led to insist that the manure of different farms and even of different animals may differ chiefly in respect to the proportion of water. He urged that "normal manure" from farmyards and stables, when not overcharged with straw or other litter, if completely dried at 212° F. will contain not far from 2 % of nitrogen.

228. Average composition of fresh horse-manure, with litter. (Wolff.)

Sheep-Manure.

Distinguishing Number of the Specimen.	Water. H_2O	Dry Matter. . .	Ash. . .	Potash. K_2O	Lime. CaO	Magnesia. MgO	Total Phosphoric Acid. P_2O_5	Soluble Phosphoric Acid. . .	Ammonia. NH_3	Total Nitrogen. N
300 . . .	57.60	42.40	....	....	....	....	0.44	....	....	0.72
301 . . .	67.10	32.90	....	....	....	....	0.16	....	....	0.91
302 . . .	61.60	38.40	3.90	0.84[1]	....	....	0.21	....	....	0.82
303 . . .	63.00	....	....	....	....	....	....	....	....	1.11
304 . . .	58.00	42.00	6.00	0.30	1.50		0.60	....	....	0.75
305 . . .	73.13	26.87	6.59	....	....	....	....	....	....	0.95
306 . . .	73.66	26.34	13.69	0.44	1.39	0.49	0.81	....	0.03	0.63
307 . . .	64. to 73.	26. to 37.	10. to 12.	1.0 to 1.1	....	....	0.2 to 0.4	....	....	0.7 to 0.8
308 . . .	64.60	35.40	3.60	0.67	0.33	0.18	0.23	....	....	0.83
309 . . .	69.30	30.70	6.69	0.77	0.60	0.06	0.21	....	0.45	0.61
310 . . .	70.27	29.73	....	0.37	....	....	0.47	....	....	0.60
311 . . .	75.60	24.40	....	0.87	....	....	0.34	....	....	0.51
312 . . .	67.30	32.70	....	1.71	....	....	0.62	....	....	0.65
313 . . .	65.00	35.00	....	1.54	....	....	0.31	....	....	0.76
314 . . .	68.30	31.70	....	1.26	....	....	0.26	....	....	0.51
315 . . .	59.52	....	....	0.59	....	....	0.39	....	....	0.77
Goat-Manure.										
350 . . .	46.00	54.00	....	....	....	....	....	....	....	2.16
Hog-Manure.										
375 . . .	81.40	18.60	....	....	....	....	....	....	....	0.63
376 . . .	80.00	20.00	3.00	0.50	0.30		0.45	....	....	0.60
377 . . .	72.40	27.60	2.60	0.60	0.08	0.09	0.19	....	....	0.45
378 . . .	80.57	19.43	....	1.86	....	....	0.19	....	....	0.71
379 . . .	84.00	16.00	....	....	....	....	0.62	....	....	0.70
380 . . .	....	....	....	....	....	....	0.28	....	....	0.37
381 . . .	74.13	25.87	....	0.32	....	....	0.39	....	....	0.84
382 . . .	65.23	34.77	9.04	0.10	1.48	0.12	0.81	....	0.02	0.58

[1] K_2O and Na_2O.

300. Dung alone of sheep fed on about 2.2 lb. of hay per diem and yielding about 5 lbs. of total solid and liquid excrement. (Boussingault.)

301. Mixed dung and urine of the animals of No. 300. (Boussingault.)

302. Fresh manure of sheep fed with hay and bedded with half a pound of straw. (Boussingault, in Muntz and Girard, "Les Engrais," **1.** 240.)

303. Mixed excrement of sheep. (Payen and Boussingault, *loc. cit.*)

304. Dung of sheep fed on about 2 lb. of hay per diem. (Stoeckhardt in his Chemische Feldpredigten, 1856, p. 84.)

305. Fresh sheep's dung. The animals were fed upon roots in an old pasture. (Voelcker, Roy. Ag. Soc. Jour., 1858, **18.** 118.)

306. Sheep-manure that had been kept three years in a heap. It was completely decomposed; was a black, greasy mass, and had more of an earthy than an animal smell. (Voelcker, Roy. Ag. Soc. Jour., 1858, **18.** 114.)

307. Sheep-manure that had been trodden firmly in stalls; as used for manuring tobacco at Wageningen, in Holland. (A. Mayer in his Lehrbuch, **2.** 179.)

308. Average composition of fresh sheep-manure with litter. (Wolff.)

309. Sheep-manure. (Bretschneider.)

310. Dung alone of sheep fed with from 3.3 to 4.4 lb. of lucern hay and 6.6 lb. of beets per day. (Muntz and Girard.)

311. Dung and urine of sheep, of about 90 lb. weight, fed with 2.2 lb. of lucern hay and 2.2 lb. of beets, and yielding 4.5 lb. of mixed solid and liquid excrement per day. (Muntz and Girard, "Les Engrais," **1.** 198.)

312. Sheep manure, from mixed food. (Muntz and Girard, "Les Engrais," **1.** 242.)

313. Manure from sheep fed upon lucern hay. (Muntz and Girard.)

314. Manure from sheep fed upon green cut lucern. (Muntz and Girard.)

315. Fresh manure of sheep fed liberally in pens and bedded with enough cut wheat-straw to keep them clean. (G. C. Watson, U. S. Exp. Station Record, **5.** 387.)

350. Mixed dung and urine of goats. (Payen and Boussingault.)

375. Mixed dung and urine of hogs. (Payen and Boussingault.)

376. Dung alone of swine on winter food. (Stoeckhardt in his Chemische Feldpredigten, 1856, p. 84.)

377. Average composition of fresh hog-manure, with litter. (Wolff.)

378. Hog-manure from Ferrières (France). The animals were fed on potatoes and barley, and it was reckoned that the cost of producing the manure was $1.62 the ton. (Gassend, Biedermann's Centralblatt, 1882, **11.** 640.)

379. Dung alone of a hog eight months old, of 132 lb. weight, that was fed with 15.5 lb. of cooked potatoes per diem and yielded 2.2 lb. of dung. (Boussingault, Mémoires, p. 169.)

380. Mixed dung and urine of the hog No. 379, which produced 2.2 lb. of dung and 7 lb. of urine per diem. (Boussingault, *loc. cit.*)

381. Fresh manure of pigs richly fed and bedded liberally with cut wheat straw. (G. C. Watson, U. S. Exp. Station Record, **5.** 388.)

382. Manure produced by swine fed on garbage and corn-meal; it had been exposed to the weather as it lay in the sties. (Report Conn. Agric. Station, 1890, 71.)

URINE OF NEAT CATTLE.

Distinguishing Number of the Specimen.	Water.	Dry Matter.	Ash.	Potash.	Lime.	Magnesia.	Phosphoric Acid.	Ammonia.	Total Nitrogen.
400 . . .	88.28	11.72	1.47	....	....	....	....	....	0.45
401 . . .	92.10	7.90	3.56	1.32 or 2.04	....	....	trace	....	0.97
402 . . .	92.00	8.00	2.00	1.40	0.15		....	....	0.80
403 . . .	89.79	10.21	....	1.57	....	....	trace	....	0.78
404 . . .	95.85	4.15	....	0.60	....	....	0.01	....	0.13
405 . . .	88.27	11.73	....	1.69	....	....	0.01	....	1.54
406 . . .	....	....	....	1.36	....	....	0.02	....	0.74–1.20
407 . . .	....	....	....	1.39	....	....	....	....	....
408 . . .	....	....	....	1.27	....	....	0.02	....	1.17
409 . . .	....	....	....	1.67	....	....	0.03	....	0.51

400. Pure cow's urine from the animal described under No. 1. (Boussingault.)

401. Pure urine from a cow fed upon rowen and potatoes. (Boussingault, Mémoires, p. 177.)

402. Urine of cows fed in winter on hay and potatoes. (Stoeckhardt.)

403. Urine alone from the animal described under No. 7. (Muntz and Girard.)

404. Urine alone from the animal described under No. 8. (Muntz and Girard.)

405. Urine alone from the animal described under No. 9. (Muntz and Girard.)

406. Urine alone from the cows, No. 10. (Muntz and Girard.)

407. Many samples of cows' urine from animals fed either with green cut forage or with hay and oil-cake. (Audoynaud and Zacharewicz, Hoffmann's Jahresbericht, 1886, p. 217.)

408. Fresh cows' urine, average of many analyses on varied foods used throughout the year. (Hansen, U. S. Exp. Stat. Rec., V., No. 5, p. 524; Biedermann, 1894, 163-165.)

409. Average of analyses made from time to time in the course of a foddering experiment which lasted eight weeks, of dung-liquor from cows. As the liquor contained no water other than that excreted by the animals, it may be regarded as being of unusually high grade. (Kuehn, cited in Heiden's Duengerlehre, 2d edition, 2. 109.)

URINE OF HORSES.

425 . . .	91.08	8.92	2.66	1.38	....	....	0.00	....	1.48
426 . . .	79.10	20.90	....	....	....	....	....	....	2.61
427 . . .	89.00	11.00	3.00	1.50	0.80		0.00	....	1.20
428 . . .	....	....	....	0.90	....	....	trace	....	1.52
URINE OF SHEEP.									
440 . . .	86.50	13.50	....	....	....	....	0.01	....	1.31
441 . . .	86.50	13.50	3.60	2.00	0.60		0.05	....	1.40
442 . . .	....	....	....	1.72	....	....	trace	....	0.89
URINE OF HOGS.									
475 . . .	....	....	1.25	0.72	....	....	0.04	....	0.23
476 . . .	97.30	2.72	3.90	1.69[1]	....	....	0.20	....	0.78
477 . . .	97.50	2.50	1.00	0.20	0.05		0.13	....	0.30

[1] K_2O and Na^2O.

425. Urine of a horse fed with oats and green cut clover. (Boussingault, Mémoires, p. 179.)

426. Urine of horses. (Payen and Boussingault.)

427. Urine of horses fed on hay and oats. (Stoeckhardt, *loc. cit.*)

428. Urine of horses. (Audoynaud and Zacharewicz, as cited in Dehérain's Chimie Agricole, p. 673.)

440. Urine of sheep consuming about 2.2 lb. of hay per diem and yielding about 5 lb. of mixed dung and urine. (Boussingault.)

441. Fresh urine of sheep fed with about 2 lb. of hay per diem. (Stoeckhardt.)

442. Urine of sheep fed with from 3.3 to 4.4 lb. of lucern hay and 6.6 lb. of beets per diem. (Muntz and Girard.)

475. Fresh urine of a hog eight months old, of 132 lb. weight, that was fed with 15.5 lb. of cooked potatoes per diem and yielded 7 lb. of urine and 2.2 lb. of dung. (Boussingault, Mémoires, p. 169.)

476. Fresh urine of hogs fed with cooked potatoes and bedded with 1 lb. of straw per diem. (Boussingault, cited by Muntz and Girard, "Les Engrais," **1.** 240.)

477. Fresh urine of hogs fed chiefly on potatoes with thin swill. (Stoeckhardt.)

Dung Liquor.

300 . . .	96.89	3.11	....	....	....	....	....	....	0.72
301 . . .	99.60	0.40	....	....	....	....	....	....	0.06
302 . . .	....	....	....	0.44	....	....	0.02	....	0.43
303 . . .	98.20	1.80	1.10	0.49	0.03	0.04	0.01	....	0.15
304 . . .	....	....	....	....	....	....	....	....	0.19 to 0.22
305 . . .	99.11	0.89	0.52	0.27	....	....	0.01	0.06	0.05
	99.25	0.75	0.37	0.20	....	....	trace	0.15	0.11
	99.13	0.87	0.52	0.22	....	....	0.01	0.02	0.03

300. Mixed urine of four animals, i. e., fresh barnyard-liquor. (Payen and Boussingault, cited in Gasparin's Traité, **1.** 683, 684.)

301. Barnyard-liquor. (Payen and Boussingault, *loc. cit.*)

302. Average of many analyses of liquid manure from the cistern into which the cows' urine (No. 408) flowed. As kept in tight covered tanks, a loss of about 2 % per month of the nitrogen of the urine was noticed. (Hansen, *loc. cit.*)

303. Average composition of dung-liquor. (Wolff.)

304. Flemish liquid manure. (Payen and Boussingault.)

305. Three samples of dung-liquor. (Cited by Dehérain in his Chimie Agricole, p. 697.)

Nessler examined dung-liquor from 7 different localities, to exhibit the relations between potash and chlorine. His results are given in the following table.

	100 c.c. of the sample contained grm. of					The Sp. Gr. was
	Nitrogen.	Phosp. Acid.	Potash.	Chlorine.	Soda.	
A. . . .	0.070	0.007	0.232	0.040	0.016	1.0056
B. . . .	0.076	0.016	0.539	0.206	0.060	1.0118
C. . . .	0.041	0.014	0.200	0.115	0.071	1.0056
D. . . .	0.650	0.022	0.776	0.144	0.070	1.0350
E. . . .	0.480	0.050	1.100	0.110	0.100	1.0260
F. . . .	1.050	0.073	0.742	0.280	. . .	1.0510
G. . . .	0.320	. . .	0.890	0.194	0.120	1.0220

Voelcker long ago made elaborate analyses of two samples of dung-liquors, the one coming from an old heap of manure and the other from a recent heap. The old dung-heap consisted of a well rotted mixture of horse-manure, manure from neat cattle that were fatting in box-stalls, and manure from sheep-pens. The sample examined was collected in rainy weather and was known to be diluted to a considerable extent with rain-water. It was of a dark brown color, and contained neither free ammonia nor free sulphuretted hydrogen. It exhibited a neutral reaction, but on boiling the liquid its reaction became alkaline ; soluble bicarbonates which were held in solution were decomposed by the heat, and both ammonia and carbonic acid were given off freely.

On adding muriatic acid to the dung-liquor it effervesced freely, humic acids were precipitated in abundance, and a most disgusting smell was made manifest, but no sulphuretted hydrogen could be detected. It appeared from this reaction that the color of the original liquor was due to the presence of humates of potash, soda and ammonia. It was noticed that so long as the dung-liquor was kept cool no free ammonia escaped from it, but that on heating the liquid somewhat, ammonia began to be given off. The analysis showed that the liquor contained noteworthy amounts of soluble phosphates and that it was rich in potash salts.

The other dung-heap was composed chiefly of a mixture of fresh horse, cow and hog manure. The liquor from it was collected at a time when no rain had fallen for several weeks, and was consequently concentrated. This liquid was very dark colored and of highly offensive odor, though it contained no sulphuretted hydrogen. It was neutral to test-papers, but on heating it ammonia escaped, though in much smaller quantities than came from the liquor that had drained from the old heap.

There was found in an imperial gallon of these drainings the following numbers of grains of the several constituents.

	Old Heap.	New Heap.
Ammonia expelled by boiling	36.25	15.13
Ammonia not expelled by boiling	3.11	
Ulmic and humic acids	125.50	. . .
Carbonic acid expelled by boiling	88.20	. . .
Other organic matters	142.60	716.81
[Nitrogen in these organic matters	3.59	31.08]
Soluble silica	1.50	9.51
Phosphate of lime with a little phosphate of iron	15.81	72.65
Carbonate of lime	34.91	59.58
Carbonate of magnesia	25.66	9.95
Sulphate of lime	4.36	14.27
Chloride of sodium	45.70	101.82
Chloride of potassium	70.50	60.64
Carbonate of potash	170.54	297.38
In the gallon	764.64	1357.74

The liquor from the new heap was almost twice as concentrated as that from the old heap, since, as it happened, the latter had been diluted to a considerable extent with rain-water. But in spite of this fact, there was less than half as much ammonia, in the form of ammonium salts, in the fresh liquor (15 grains) as in the old (39 grains). The large amount of nitrogen in organic combination found in the liquor from the new heap shows that comparatively little decomposition had occurred there as yet; while from the character of the drainings of the old heap it appeared that noteworthy amounts of the organic nitrogen had in the course of time changed to compounds of ammonia.

Mere traces of nitrates were detected in the liquor from the fresh manure, while there were noteworthy quantities in the liquor from the rotten dung.

The liability of soluble organic matters to suffer decomposition is illustrated by the fact that while the amount of inorganic matters (nearly 369 grains) in the old liquor exceeded the amount of organic matters (about 356 grains), the relations were reversed in the fresh liquor, where there were some 626 grs. of ashes to 717 grs. of organic matter. It is to be observed that dung-liquor differs from urine in several respects. For example, the drainings of manure-heaps contain considerable quantities of soluble phosphates, although ordinarily no appreciable quantity of phosphoric acid can be detected in the urine of cows or horses.

HUMAN EXCREMENTS.

Distinguishing Number of the Specimen.	Water.	Dry Matter.	Ash.	Potash.	Lime.	Magnesia.	Total Phosphoric Acid.	Soluble Phosphoric Acid.	Ammonia.	Total Nitrogen.
	H_2O	. .	. .	K_2O	CaO	MgO	P_2O_5	. .	NH_3	N
A. Dung .	75.00	25.00	1.6	0.35	0.55		0.55	....	....	0.70
B. Urine .	96.00	4.00	1.1	0.20	0.03		0.15	....	....	1.00

A. Average composition of fresh solid excrement of well fed men. (Stoeckhardt, Chemische Feldpredigten, 1856, p. 95.)

B. Average composition of fresh urine from well fed men. (Stoeckhardt, *loc. cit.*)

It is to be noted that in spite of the large proportion of water in urine, the amount of solid matter in the urine voided by a man in a day is about one-third larger than the quantity of dry matter in the solid evacuations of a day.

The items here given in the table relating to human excrement are for the sake of comparison merely. The question of the composition of fæcal matter will be considered more particularly in the chapter on Night-Soil.

Average Composition of Manures.

Having regard to the more trustworthy of the analyses given in the tables, it will be seen that 100 lb. of good farmyard-manure usually contain from 70-odd to 80-odd lb. of water, or say three-quarters of the whole weight of the manure, and that it is safe to allow for each 100 lb. of the manure as much as 0.04 to 0.06 lb. of nitrogen, from 0.15 to 0.35 lb. of phosphoric acid, some 0.4 to 0.6 lb. of potash, 0.5 to 0.9 lb. of lime, and about 0.2 lb. of magnesia. The large amount of water is so to say essential, since the manure would not ferment properly in the absence of moisture.

The small percentage of nitrogen in farm-manure, as compared with other nitrogenous fertilizers, is well shown by the following table: —

Ordinarily there is in Commercial	About per cent of Nitrogen.	Ordinarily there is in Commercial	About per cent of Nitrogen.
Sulphate of ammonia	20–21	Bone-meal	3–4
Nitrate of soda	15–16	Horn-waste	8–14
Nitrate of potash	11–12	Woolen rags	10–12
Dried blood	10–12	Wool-waste	3–7
Tankage	7–10	Soot	1.3–2.5
Fish-scrap	6–10	Peat	1.5–2
Peruvian guano	7–9	Hen-manure	1–2
Oil-cakes	5–8	Farm-manure	0.4–0.6

Urine a forcing Manure.

It will be noticed that the comparatively large proportion of nitrogen in the urine of animals corroborates the common view of farmers, that urine is a "forcing manure." Fresh urine is, in fact, a very valuable nitrogenous fertilizer. In cases where it can be brought immediately to the crops, each pound of this nitrogen may be rated at as high a price as has to be paid for the pound of nitrogen in guano or in nitrate of soda. All of the nitrogen in urine is, of course, in the soluble form, and it may be regarded as immediately available as plant-food. The same may be said, also, of the potash salts, which constitute the other fertilizing constituents of the urine of herbivorous animals. It is to be observed, moreover, that a large proportion of the potash in the food of these animals passes out from them in the urine, while the phosphoric acid, and most of the lime and magnesia, go out in the dung.

The nitrogen in mere dung is of very inferior quality to that in urine, since most of it is insoluble, and in a condition unassimilable by plants. It is contained chiefly in the undigested, not to say indigestible, portions of food which have been expelled by the animal as useless for his purposes, while the nitrogen in urine is all in solution. Considered from this point of view, the money value of the dry matter in urine is far larger than that in dung, as may readily be seen by computing the value of the constituents in 100 or 1,000 lb. of both, in accordance with the data given on a previous page. It is true, none the less, practically, that, in its ordinary condition of dryness, first-rate farmyard-manure is a powerful nitrogenous fertilizer. Thus, Dehérain found, in two samples of "normal mixed manure" from the farmyard at Grignon, the following percentages of nitrogen: —

Nitrogen in the form of carbonate of ammonia	0.045	0.030
" " " non-volatile salt of ammonia	0.015	0.010
" in organic matter	0.660	0.370
Total nitrogen	0.720	0.410

Alkalinity of Horse- and Cow-Urine.

Another point to be noticed is, that the urine of cows and horses has a distinctly alkaline reaction, both when fresh and after fermentation has set in. The fresh urine of herbivorous animals is alkaline, because it contains bicarbonate of potash, as Boussingault insisted long ago, while the carbonate of ammonia in stale urine is even more strongly alkaline. Both these facts are important, because, as will be seen hereafter, most fermentations are promoted by the presence of alkaline liquids.

A good general idea of the condition in which nitrogen exists in fresh urine may be got from the analyses of Boussingault, given in the following table, though it is to be said that the proportion of urea or of hippuric acid may vary considerably, according to the food: —

In fresh urine there was present of	Cow.[1]	Horse.[2]	Hog.[3]
Urea	1.85	3.10	0.49
Hippurate of potash	1.65	0.47	0.00
Lactate of potash	1.72	1.13	not estimated.
Lactate of soda	...	0.88	
Bicarbonate of potash	1.61	1.55	1.07
Carbonate of magnesia	0.47	0.42	0.09
Carbonate of lime	0.06	1.08	traces.
Sulphate of potash	0.36	0.12	0.20
Chloride of sodium	0.15	0.07	0.13
Silica	traces	0.10	0.01
Phosphate of potash	0.00	0.00	0.10
Water and loss	92.13	91.08	97.91

All these urines were strongly alkaline, from the presence of bicarbonate of potash. It is noticeable how large a proportion of the 8 or 9 % of solid matters contained in the urine of the cow and the horse consists of urea. The observations of Audoynaud and Zacharewicz corroborate those of Boussingault, for they found from 16 to 26 grammes of urea (on the average of many trials, 21.96 grms. of urea, equal to 10.2 grm. of nitrogen) to the litre in the urine of cows fed with green fodder and with hay and oil-cake. They found, also, as much hippurate of potash as would contain another grm. of nitrogen; i. e. they found 11.2 grm. of nitrogen in all. The proportion of hippuric acid is subject to wide variations, according to the food, von Bibra says from 0.55 to 1.20 %. Some chemists have held that fodder rich in lignin specially tends to the production of hippuric acid. Henneberg and Stohmann found most hippuric acid (2.1 to 2.7 %) in the urine of oxen that were fed with the straw of wheat or oats to which a little bean-meal had been added. With hay alone, they found from 1.2 to 1.4 % of hippuric acid. As the mean of 8 trials, they found in cow's urine 0.85 % of hippuric acid and 1.1 % of urea. As a rule, the addition of easily digestible foods to the ordinary hay or straw ration diminished the hippuric acid and increased the proportion of urea. In the urine of sheep fed upon hay and straw, there appears to be actually more hippuric acid than urea. Urea contains nearly half its weight of nitrogen, uric acid about one-third of its weight, and hippuric acid less than 8 %.

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[1] The cow was fed upon rowen and potatoes.

[2] The horse was fed with green cut clover and oats.

[3] The hog was fed exclusively on cooked potatoes, but neither hippuric nor uric acid appeared in the urine, not even on feeding with green cut clover.

Generally speaking, the proportion of urea in urine is intimately connected with the digestion and utilization of nitrogenized foods. To show how widely the amount of it may vary according to the character of the food, the following table is appended. It relates to human urine, as investigated by Lehmann, and gives the weight in grammes of the stated substances which were discharged in the urine of a healthy adult in 24 hours: —

	Solid Constituents.	Urea.	Uric Acid.	Extractive Matters and Salts.
On a mixed diet	67.82	32.50	1.18	12.75
On an animal diet. . . .	87.44	53.20	1.48	7.31
On a vegetable diet . . .	59.24	22.48	1.02	19.17
On a non-nitrogenized diet	41.63	15.41	0.74	17.13

Practical Value of Dung-Liquor.

The dark-colored liquor which drains out from old dung-heaps is known to possess great fertilizing power, and the rank growth of weeds and grass in places wet by it capitally illustrates the absurdity of allowing any of it to go to waste, as happens far too frequently. As the table of analyses shows, dung-liquor does not usually hold any very large quantity of matter in solution, in spite of its dark color. In special trials made to test this point, Dehérain found no more than from 2 to 4 % of dry matter. Dung-liquor has an alkaline reaction, due to the presence of carbonate of ammonia and carbonate of potash, and it effervesces strongly on being mixed with an acid.

Field Experiments with Dung-Liquor.

To test the fertilizing power of barnyard-liquor as applied to grass, Wollny divided three grass-plots in such wise that the grass was mown for hay on half the area of each plot, while the rest was allowed to go to seed. Half the grass and half the seed-hay was manured with barnyard-liquor at the rate of 600 gallons to the acre, while the other half received no manure. The results of these experiments are given in the table: —

	The Grass Plot.		The Seed Plot.		
	Grass. lb.	Hay. lb	Seed. lb.	Straw. lb.	Total. lb.
French ray-grass (Avena elatior) manured with barnyard-liquor	9,209	2,123	80	2,890	6,830
Same, no manure	5,648	1,690	51	2,304	5,321
English ray-grass (Lolium perenne) manured with barnyard-liquor	5,520	1,364	486	1,210	4,692
Same, no manure	1,720	508	172	510	1,698
Festuca pratensis, manured with barnyard-liquor	6,672	1,669			
Same, no manure	2,240	671			

On analyzing the hay of the French ray-grass, it appeared that the parcel which had been manured was of much better quality than that which had received no manure, in that it contained a much larger proportion of nitrogenized matters, viz. 9⅔ % albuminoids against 7⅓ % in the unmanured hay.

Use of Liquid Manures.

There are several countries where liquid manures are esteemed to be superior to all others. In some parts of Switzerland, for example, in Holland, and particularly in Belgium, liquid manure is used freely. Even in recent years Dr. Voelcker has noticed that the Belgian farmer, as a rule, is anxious to obtain as much liquid manure as possible, and to this end he rather invites than prevents the rains which fall from the unguttered roofs of the farm buildings to find their way to the dung-heap.

Not only does he carefully collect in tanks the drainings of dung-heaps and liquid refuse from the house, but it is an old custom in that country to prepare liquid manure expressly for certain purposes by mixing dung with water. One plan is to stir oil-cake into the tank which contains the mixture of dung and water, and to leave the mixture to itself during 3 or 4 weeks in order that it may undergo fermentation before it is applied to the land.

This custom is recognized to be advantageous in so far as the liquid condition of the manure permits its even distribution throughout the soil, so that, as is the case with superphosphate of lime, the plant-roots may everywhere find a supply of nutriment. It is a matter of practical experience, however, that liquid manure is not adapted to all kinds of crops. Generally speaking, it may be applied to leafy crops, other than legumes, but not to those which are to bear seeds, though Nielson finds it to be well suited to crops of seed-grass.

When properly diluted, it may often do good service upon backward grain-crops early in the spring. It is not to be recommended for leguminous plants, but for the kitchen garden it has great merit. Many vegetables may be greatly helped by it, and it is really in gardens that it is used chiefly. In forcing cauliflowers, for example, it is customary in some localities to scrape out a little trench around the root of each plant, and to pour into it one or two quarts either of dilute liquid manure or of diluted night-soil. In some places liquid manure is used with advantage upon grass-fields which are mown several times a year, and upon fodder corn, mangolds and other roots.

In Denmark, according to Nielson, liquid manure should be applied in the spring. If this be done, it serves an excellent purpose on winter grain, on the true grasses, especially those which grow quickly, and on beets. In his experiments it produced little effect when applied in the autumn to grass, or when put upon fallow land, at that season, which was to be seeded to grain. He urges that it would be well, if it were possible, when preparing land for grain in the autumn, to apply stable manure that contained no dung-liquor, and to apply the latter to the young grain in the spring. On the growth of leguminous plants dung-liquor had very little influence, no matter whether it was applied in the spring or in the autumn. On testing the practice, which prevails in some parts of central Europe, of applying dung-liquor to old fields of lucern, Nielson found that it was not to be commended. He condemns it as irrational.

Liquid Manure is Costly.

Since the preparation, preservation, and application of the liquid manure involves the necessity of tolerably costly cisterns and a great deal of labor and oversight, the use of it has been confined hitherto, with rare exceptions, to countries where the processes of agriculture depend on what may be called horticultural methods. In other words, liquid manure is used in a few countries where the land is divided into gardens rather than into farms. It has been suggested also that the use of liquid manure, in the countries where it is habitually employed, may have originated in a lack of straw or other litter wherewith to bed the animals and to absorb their urine. Moreover, it has been argued, with much truth, that "The chief reason why so much trouble is taken by the Flemish farmer to save every particle of liquid, as well as of solid manure, and why so much time and labor are spent in its management, is simply that the small farmer has an excessive dislike to buying anything. Mistaking bulk for quality, his argument is, 'The more manure I can make, the less guano I shall need to buy.'" (Jenkins.)

But it is none the less true, that the Belgian use of diluted dung-liquor teaches a highly important lesson in respect to the mode of action of animal manures, and as to their real superiority over most other fertilizers, though it is to be presumed that a good part of the efficacy of liquid manure is to be attributed to the rapid nitrification of much of the nitrogen which is contained in it.

A subordinate point to be noted is, that, for very high farming, liquid manure properly diluted has a certain advantage over guano, in that there is no risk of the crops being "burned" by it, as they might be by guano in case the land were to become dry soon after the application of this fertilizer. In cases where it is desirable to avoid the cost of transporting large quantities of water, the crude dung-liquor may be hauled directly to grass-land in showery weather. It is said, indeed to be customary in Switzerland to apply dung-liquor as such in the spring, and to mix it with water only in very hot weather.

Some idea of the influence of dilution in promoting nitrification may be got from the results of Warington's experiments on the nitrification of urine. He found that the strength of a urine solution which can be nitrified is limited by the proportion of carbonate of ammonia which will be formed in it from the urea during the first stage of the action. Thus, when urine in different degrees of dilution was "seeded" with soil — 1 grm. of soil being added to 100 c. c. of the liquid — nitrification began in 11 days in a 1 %

solution, in 20 days in a 5 % solution, in 62 days in a 10 % solution, and in 90 days in a 12 % solution. The alkalinity of the last-named solution was equal to 447 mgr. of ammonia to the litre when nitrification began in it, which was very near the limit of tolerance, for nitrification appears to be impossible in solutions having a degree of alkalinity equal to 500 mgr. of ammonia to the litre. It is to be noted, however, that solutions of carbonate of ammonia much stronger than those here cited would be nitrified when put upon a fertile soil, since the ammonia would be absorbed and "fixed" by the soil, and its alkalinity would thus be annulled or diminished.

Number of Cords of Manure to the Acre.

The statements of practical men vary not a little as to the quantity of manure to be applied to an acre of land. New England farmers commonly regard 8 or 10 cords to the acre as an adequate dressing for field purposes, and they probably rarely use more than 12 cords or less than 6. Market gardeners, however, in the vicinity of Boston, apply horse-manure from the city stables at the rate of 20, 30, 40, or it may even be 60 cords to the acre, — to celery, for example; though some of them are said to now use manure at the rate of 10 or 12 cords, together with 1,000 lb. of guano, or 2,000 of bone-meal, whereby, as is claimed, a great saving in the first cost of fertilization is effected.

One advantage gained by the gardeners in using such large quantities of manure, is that the soil is kept soft and moist, so that the roots, even of the most tender vegetables, can penetrate it in all directions with great freedom. On the other hand, there is a disadvantage in that the flavor of vegetables fed with excessive quantities of rank manure may be somewhat impaired, even when pains are taken to protect the leaves from actual contact with the dung. Complaints have often been made, in Europe, that night-soil may act in this way when too much of it is applied to the land; and it is notorious that cows commonly refuse to eat the luxuriant herbage which grows about heaps of manure, as well as the rank grass that springs up around clots of their own dung in the fields.

The famous old German writer, Thaer, regarded 17 or 18 tons to the acre as an abundant dressing; 14 tons he called good, and 8 or 9 tons light. Other German authorities speak of 7 to 10 tons as light, 12 to 18 tons as usual, 20 or more tons as heavy, and 30 tons as a very heavy application.

Weckherlin calculated that, for two exhaustive crops, 12 tons of manure should be applied to the acre, and for three exhaustive crops 18 tons. In the northern departments of France, for rotations of three years, 26 tons to the acre is regarded as a very heavy manuring; 22 tons is called a heavy dressing, and 18 tons good; 13 tons are ordinarily applied, and no more than 8 or 9 tons is called a light dressing. (Muntz & Girard.) Gasparin speaks of 13 tons to the acre as a simple ordinary manuring at the South of France. He noticed in European countries where the three-course rotation is practised, and the land is manured only once in the three years, that sometimes 24 tons to the acre, and sometimes 13 tons, were regarded as complete manurings.

There must always be some uncertainty in statements relating to the quantity of manure required to dress an acre of land, because different samples of manure may differ considerably as to their quality. It is held by practical men that manure from stables where horses are highly fed, either for pleasure or for hard work, from pig-pens, from stall-fed cattle that get oil-cake or grain, and from cow-stables in or near cities, has more than twice the strength or power of manure that has been produced by poorly-fed animals.

In case the soil is rich enough and moist enough to be worthy of heavy dressings of manure, there will be a manifest advantage in applying a considerable quantity of it all at once, because of the economy of labor. The land will need very much the same amount of ploughing, harrowing, and cultivating for a given course of crops, no matter how much manure has been put upon it; and, as a general rule, any soil needs to be saturated with plant-food, in order that it shall produce first-rate crops.

Weight of the Cord of Manure.

Boussingault has determined the weight of manure as follows: —

	Wt. of a cubic yard. lb.	Wt. of a cord. lb.
Very strawy farmyard-manure, as thrown from the stable	500 to 675	2,400 to 3,200
The same manure, still fresh, but well settled	1,200	5,600
Half rotted	1,400	6,400
Well rotted, moist and compressed	1,500	7,200
Well rotted manure, of young cattle fed with hay, taken from a N. E. barnyard. It contained one-quarter of its weight of clay. (S. W. Johnson.)	1,080	5,100

Tolerably fresh horse-manure, without long straw (S. W. Johnson.)	945	4,535
Perfectly fresh horse-manure, without any litter, trodden hard. (H. Stewart).	1,728	8,190
Fresh cow-manure. (S. W. Johnson)	1,700	8,000
" " " packed hard. (H. Stewart)	1,796	8,500
Partly rotted cow-manure, saturated with urine from bottom of a heap. (H. Stewart)	1,897	8,992

Waring, at Newport, R. I., found that a well-trodden cartload of livery-stable manure, on which hogs had been constantly working, but which contained the usual proportion of straw, weighed 3.5 tons to the cord.

Generally speaking, cow-manure may be estimated to weigh 3.5 tons, or rather more, to the cord. When very good, it may weigh 4 tons. Horse-manure, as hauled from stables in Boston, weighs some 2.5 tons, or perhaps 3 tons, to the cord.

Relation between the Constituents of Manure applied and Crops removed.

It was remarked many years ago by Chevreul, that, "Manure is the complement of the soil." But this dictum must not be taken in too narrow a sense, for manures serve several other purposes beside that of supplying directly to the land the chemical substances which are contained in them. If the argument were, that manure should be applied in quantities sufficient to give to the land as much potash and phosphoric acid as the crops carried off, the amount to be used could be ascertained by simply weighing and analyzing both the crops and the manure, and contrasting the results of the analyses. Heiden has made such a comparison for a farm at Waldau, and has obtained the results which here follow. In the course of ten years, the crops grown in the rotation practised at Waldau carry off from each Morgen (= 0.631 acre) of land 263 German pounds of potash, 121 lb. of phosphoric acid, and 329 lb. of nitrogen.

But Voelcker found in 100 lb. of fresh farmyard-manure 0.672 lb. of potash, 0.315 lb. of phosphoric acid, and 0.643 lb. of nitrogen; while in 100 lb. of well-rotted manure, six months old, he found 0.491 lb. of potash, 0.449 lb. of phosphoric acid, and 0.606 lb. of nitrogen. Hence, to supply the potash of the Waldau crops, some 20 or 25 tons of manure would be needed; — to supply the phosphoric acid, from 13 to 19 tons; and to supply the nitrogen, 26 or 27 tons.

Practically, it was customary at Waldau to apply 25 tons of manure to the Morgen of land in the course of the ten years, in 2½ instalments, so that the land was continually made richer, both as regards potash and phosphoric acid, while in respect to nitrogen about as much was put back upon the land as was taken off.

Here, manifestly, is an instance of the old custom of using enough stable-manure to supply the crops with the nitrogen they need, as well as with ash-ingredients, and the figures just given well illustrate the unreasonableness of pushing this practice to such an extreme, after the land has once become fully charged or saturated with manure.

Wherever such large quantities of manure as the foregoing are applied to land, the influence of the fertilization may be felt even after many years. It has been shown by the experiments of Lawes and Gilbert, even more conspicuously than by the observations of numberless farmers, that the accumulation of unexhausted fertility may be very large when manure is applied frequently and in excess of the needs of the current crops. In some cases, many years of cropping would be required in order to remove the excess of plant-food thus accumulated.

After having applied farmyard-manure to a barley-field during 20 years in succession, at the rate of 14 long tons to the acre, Lawes and Gilbert divided the field into two, and they continued to apply the manure, as before, to one half of the land, while no manure was put upon the other half. Meanwhile, barley was grown continually upon both the fields, as before, and it appeared that every year, during the next twelve years, the unmanured crops of barley averaged 34.5 bushels to the acre. The last of these crops, grown in a rather favorable season, exceeded 35 bushels, whence the inference that a long series of years must elapse before the fertility imparted by the manurings of the 20 years would be wholly exhausted. Marshall has mentioned an instance in which the effect of dung that had been applied to the soil of the Cotswold hills in England lasted nearly 50 years.

It will be noticed, that no account is here taken of the natural waste of nitrogen from land that is under tillage. But it is now known that, while the potash and the phosphoric acid in manures are fixed in the earth by combining with silicates, humates, and oxides which they find there, much of the nitrogen is not thus held, but tends to waste away slowly by being converted to nitrates, which are leached out by rain and carried off in the drain-water.

Of course it must have happened in these instances, as in ordinary farm experience, that not all the nitrogen actually carried off by the crops came from the manure. Some of it must have been derived from the humus of the soil, and another portion doubtless had been obtained from the air by the leguminous crops which were grown occasionally in the rotations.

Preservation of Manure.

The questions are now fairly in order, What does chemistry teach as to the best means of preserving animal excrements, and of applying them to the soil? These questions, it will be noticed, include a multitude of other questions which have been much disputed; such as,—

Should manure be ploughed in long or short? that is to say, should it be applied fresh or after fermentation?

Should manure be kept moist or dry? housed, or out in the air? in heaps, or in pits? firmly trodden, or loose?

Should it be composted, or kept by itself?

Should it be spread upon land as a top-dressing, or be ploughed in? And if it be ploughed in, how deep should it be buried?

Then again, at what time of year should manure be put upon the land?

And to what kinds of crops may it well be applied directly?

How much shall be applied and how often?

And so on.

The question of preserving manure is not a little complicated by the fact that each kind of dung ferments in its own special way, so that a method which might be peculiarly well adapted for preserving one kind of manure need not necessarily be suited for preserving another kind.

To take an extreme case, for the sake of enforcing this point, it may be said that fresh human excrements are doubtless more valuable as a manure upon fertile soils than any other kind of dung; but it is exceedingly difficult to preserve them. The night-soil of cities is in no sense comparable as a manure with fresh excrements, and the various poudrettes, ta-feus, and other products prepared from night-soil, are comparatively speaking worthless; that is to say, very much better and more powerful manures can readily be bought nowadays for much less money.

The trouble is, that the nitrogenized constituents of human excrements are of such character that they begin to ferment, putrefy, and spoil rather more rapidly than so much flesh would; and it happens that during this process of fermentation the best part of the manure goes off in the form of gas.

Earth as a Preservative.

The thought lies near at hand that the excessive power, so to say, of dung so strong as that just mentioned needs to be controlled. Hence the idea, that if the dung were weakened or diluted by mixing it with inert matters, or with those that are less putrescible than itself, the tendency towards destruction might be diminished. There can be no doubt that this conception is one of great value, though it is subject to limitations and has often enough been misunderstood. Care must be taken that the earth or other diluent shall be used in such manner that air cannot gain too easy access to the manure and that the heaps may be kept somewhat compact and moist. It is known nowadays that one quick way of dissipating flesh is to bury it in a layer of charcoal or dry earth to which air has access; and it is but natural to suppose that dung rich in the constituents of flesh will behave something like flesh when exposed to similar conditions. Upon this point more will need to be said under the head of Composts.

Preservation by Drying.

Theoretically, perhaps, the most effective way of preserving human excrements would be to dry them rapidly, and to pack the compressed residue in tight, dry parcels, together with a little salt or other preservative; and a precisely similar remark would apply to other kinds of dung, though to few of them so strongly.

According to the analysis of Way, the solid part of human excrement would contain when thus dried some 6 % of nitrogen, 4½ % of phosphoric acid, and rather more than 1 % of potash; that is to say, two tons of the dry material would be worth about as much as one ton of good Peruvian guano.

Dried human urine would contain some 19½ % of nitrogen, 4½ % of phosphoric acid, and 5 % of potash.

But this supposed method of preservation is impossible under the conditions of labor and climate in which we live. As things are now, it costs very much less to import guano and potash, or to make superphosphate, than it would cost to dry the manure. It has been noticed withal by Pfeiffer and by Stutzer in respect to dung, and by S. W. Johnson as regards fish-scrap, that drying may impair the fertilizing power of the materials. At all events they found that less nitrogen could be dissolved from dried horse-dung and cow-dung and from dried fish than from the fresh materials when they were subjected to the process of artificial digestion described on a previous page.

Drying being out of the question, some other method of preventing or of hindering fermentation must be looked for; but it is hard to say which method, among those that are possible, would theoretically be the best; for the problem is an extremely complex one, and the intrinsically low value of the material forbids the expenditure either of much labor or of money for buying and applying preservative agents.

Preservation by Compression in Pits.

In all human probability, however, some system of what may fairly enough be called ensilaging the dung would come nearest to perfection; that is to say, some method of compressing the fresh manure in pits, and covering it up with weighted boards or with earth in such wise that air could not gain access to it. Practically this thing is done not infrequently — in a very crude and incomplete way, indeed — as regards cow-dung which is kept undisturbed in barn cellars in cold weather; for the portions of dung first thrown into the cellar are so covered and compressed by the dung which is subsequently thrown upon them that some parts of the heap are often found to be in tolerably fresh condition long after the dung was voided.

Hot Fermentation and Leaching are Bad.

Of course every farmer knows, though not a few of them act as if they did not, that mere dung and urine should neither be allowed to become heated unduly nor to be leached by rain. Even heaps of dung that is admixed with straw or other litter, if exposed to hot summer sunshine, would be liable to be heated and dried improperly, and to suffer fermentations such as might cause great loss of the nitrogenous constituents of the manure. Many persons have urged that, in order to hinder this excessive action, it is well to keep dung in shady places. In the North of France rows of elms are often planted expressly to shade the dung-heaps.

But beside the sun's heat in summer there is the rain thrown from farm-buildings which needs to be guarded against. In New England, this country of heavy showers and costly straw, it might well be asked whether some kinds of manure should not in general be carefully protected from rain. There have been those among us who claimed that manure should be thus protected almost as carefully as if it were hay.

Dung-Sheds and Cellars.

At one time or another some good farmers, in order to avoid the effects of sun and rain, have had rough sheds built on purpose to shield their heaps of manure. It is not a little doubtful whether such sheds can ever have repaid the cost of erecting them, but the idea of having dung-sheds is instructive, since whatever advantages such sheds may possess must plainly be shared by the barn cellars in which manure is very commonly kept in New England. In these cellars the manure is protected from rain, and sun, and frost, and wind, at the same time that it is kept moderately moist and in a condition of slow and equable decomposition. Generally speaking, the manure is subjected also to a considerable amount of admixture and compression by means of hogs that are allowed to run upon it. In a mere shed, it would manifestly be much less easy to keep the dung in such excellent condition, or to prevent it from drying out unduly in hot or windy weather.

There is one objection to the alternate wetting and drying of manure that would count against the use of airy sheds, while it would be avoided in cellars; viz., that noteworthy quantities of carbonate of ammonia may be carried off by the vapor of water as it evaporates from a manure-heap or from a barnyard pool. In experimenting upon manures, whether comparatively fresh or rotted, for the purpose of determining how much moisture is contained in them, chemists have repeatedly observed that a very considerable loss of ammonia is apt to occur during the process of drying. The ammonium carbonate is lifted as it were and carried off by the aqueous vapor.

In general, it may be said, in so far as mere rain is concerned, that there is no real need of keeping manure under cover. Any water which may fall directly upon a manure-heap, in the form of rain, is not likely to do any serious harm, while such water may be highly useful in summer. But an excess of water should be avoided, and that which runs off from the roof of the barn or stable should be led away through gutters, and should not be allowed to fall into the barnyard. Something may here be said in favor of the old New England winter practice of throwing out heaps of dung upon the north side of the barn, there to freeze into solid, stonelike masses, for it is evident that while thus frozen the manure can suffer no loss of nitrogenous matters by way of fermentation.

The keeping of swine upon stable-manure "to work it over," as the saying goes, is really a point of no small importance, both for the preservation of the chemical constituents of the dung and urine, and for improving the mechanical condition of the manure. The rooting of the swine is an effective means both of mixing the hot horse-manure with the cold cow-manure, to the manifest advantage of each, and of commingling them with whatever of straw, or leaves, or weeds, or peat, may have been used either as bedding, or have been added directly to the manure for purposes of absorption or of composting. The product obtained in this way is particularly easy of application to the fields, for it admits of even distribution and of being thoroughly mixed with the soil. There can be little doubt that hogs pick up and digest many seeds of weeds which the manure contained, or that some weed-seeds are destroyed by decay in manure upon which hogs have worked.

Litter may preserve Manure.

Several of the methods of preserving manure which are actually employed by farmers commend themselves from the chemical point of view. Thus the method in ordinary use in Massachusetts, when cows are kept in stall during the winter, of using as bedding enough straw, or leaves, or dry peat, to absorb and hold the urine that comes from the cattle, and keeping the product stored in cool cellars, as has been said.

The old German writer Block was strongly in favor of using mixtures of straw and loam for bedding neat cattle, as a means of improving their manure. He urged that, by means of alternate layers of straw or other litter and earth added fresh every day to avoid balling and impaction, the dung and urine may be absorbed and preserved most completely, i. e. with the least amount of loss.

Several other practical men have maintained that the addition of half a cubic foot of loam per head and day to the straw is advantageous. So too, the use of loam to supplement straw has not infrequently been regarded as a resource in cases where not enough straw could be procured for properly bedding the animals. Thus, when no more than 3 or 4 lb. of straw per head and day can be provided, the deficiency may be made good with 1¼ to 1½ cubic feet of earth. Similar quantities of loam have been used also, together with 6 or 8 lb. of straw, in cases where the food of the animals happened to be specially watery, even on farms where straw was to be had in tolerable abundance.

Antiquity of Loam-bedding.

It should be said that the use of loam for bedding animals, and as a means of preserving and augmenting manure, is a very old agricultural practice, which is still retained by some primitive peoples. Thus, on the Shetland and Orkney islands, the cottagers are still accustomed to scrape, from the outlying hills and sheepwalks, the scanty coating of sods and loam, and to use this material for bedding their cows in winter. Layers of the earth — together with the broken, small dry sods, and heather which has been mown for the purpose — are spread evenly every few days upon the floor of the cow-house, until the place is so full that the cattle have barely room to stand under the roof, when the whole of the compost is thrown out. It is said that the earth serves an excellent purpose as a deodorizer and as an absorbent of the urine, and that the manure obtained is of excellent quality. The system is highly objectionable, however, in that it tends to reduce large tracts of land to a condition of barrenness. The places from which the loam has been removed are left so bare and useless that the land is practically destroyed.

Even sea-sand is used in some places for bedding animals, without any addition of straw or other matters. For example, at Yarmouth, in England, in 1780, "The practice has been in use from time immemorial of littering stables with sea-sand instead of straw. As the bed becomes soiled or wet, fresh sand is scattered on, until the whole is in a degree saturated with dung and urine. The stall is then cleared and a fresh bed of sand laid in. By this means, manure of a quality singularly excellent is produced. It is fetched by farmers to a very great distance." (Marshall.)

In experiments made by Muntz and Girard, relating to the large loss of nitrogen, due to ammoniacal fermentation, from recently voided manure as it lies in the stable under the feet of animals, it was found that the waste of nitrogen could be much lessened by means of peat and of loam rich in humus. Loam was found to be a very efficacious preservative, since it reduced the loss of ammonia to the extent of 50 per cent. The loam promoted nitrification also. Straw, by itself, no matter how much of it was used, did not wholly prevent the loss of ammonia, and peat was not entirely satisfactory, though it was more efficient than straw. Mixtures of straw and peat, or of straw and loam rich in humus, would be commendable were it not for the cost of the labor involved in collecting, storing, and handling the loam.

The merit of using absorbents, proper to retain the liquid part of the manure, is illustrated by observations which have been made as to the condition of the soil beneath dung-pits, and as to the depth to which dung-liquor may soak beneath such receptacles. Heiden found, beneath a paved cow-stall, that the earth, even to a depth of nearly six feet, was wellnigh saturated with dung-liquor; and Ritthausen, on analyzing a loamy soil taken at a depth of 3 feet beneath a dung-yard, found that the earth contained 0.5 % of phosphoric acid and 0.7 % of potash. On being exposed for some time to the air, this earth took on the blue color of phosphate of iron.

Urine may be Excessive.

In general, it may be said that the question of absorbing urine is far from simple in all cases where animals are fed upon watery foods, as when cows are kept upon the liquid slop from potato distilleries, as is the case in many parts of Europe, or when cattle get large quantities of beet-pulp or turnips. Much urine may be produced, also, when cows are kept up in summer, and fed with mown clover or corn-sprouts and other juicy green foods.

For the sake of thoroughly absorbing the liquid manure, and for convenience, also, several European writers have recommended that, when steam or water-power are available, the straw should be cut to foot lengths before using it for bedding animals. The point is one of some interest, as tending to enforce the merit of leaves for this purpose. One method of using cut straw has been described as follows.

The animals are bedded, at the rate of 7 lb. per head and per day, with straw chopped into pieces 2 or 3 inches long. Behind the animals is a trough 9 inches deep and 16 inches wide, which receives the excrements and the bedding of 24 hours. Once a day the contents of this trough are thrown out, and the dung and litter are scraped from beneath the animals and trodden into the trough, there to absorb the urine of the next day. It is said that, even when the animals are fed with distillery slop, none of the liquid excrement escapes absorption.

Manure thus prepared is remarkably homogeneous, and so evenly saturated with moisture that it packs itself firmly in the dung-heap, and "keeps" admirably. On inspecting such a heap at the end of 5 months (June to December), it appeared that decomposition had hardly begun. Such manure is naturally "short," and easy to handle. It can be hauled out and worked into the land at any moment, without need of ever being forked over. On testing the absorptive power of chopped straw, of different kinds, Marek found that from 5 to 20 % more water was absorbed by it than by long straw. The greatest gain was got with the straw of spring rye, and the least with that of spring wheat.

Wet Fermentation of Manure.

One plan for preventing the waste of liquid manure is to dig a hole outside the barnyard to receive the drainage, and to throw into this hole all sorts of rubbish that is capable of absorbing liquids.

Commonly, however, when cows are fed with watery foods, so much liquid excrement is produced that special pits or cisterns have to be provided, from which the excess of liquid may be pumped up from time to time to drench the solid matter, or to be carted into the fields for use as liquid manure.

Muntz and Girard, in their experiments on the waste of nitrogen from manure, found that less of it was lost when peat or loam were used than when the animals were bedded with straw. Thus, in 2 stables, each of which contained 16 horses, 64 % of the nitrogen in the food was not recovered in the manure when straw was used for bedding, while the loss of nitrogen was only 48 % when the horses were bedded with peat. In 2 sheep-stalls, each of which held 25 of the animals, the loss of nitrogen was as follows: —

Straw bedding	50 %	of the N in the food was lost.
Loam "	26 %	" " " "
Straw and copperas . . .	48 %	" " " "
Straw and gypsum . . .	46 %	" " " "

It is noticeable that manure thus drenched with liquid, especially if it be kept in large heaps or in deep pits, appears to ferment more thoroughly and in a somewhat different way from that which is less perfectly moistened. It becomes very dark-colored, or even black, and acquires a highly offensive odor, while the straw in it loses its consistency and becomes soft and incoherent. It is to be presumed that the alkaline dung-liquor acts not only to dissolve some of the components of the straw, and serves to prevent the manure from becoming acid, but that the micro-organisms in the liquid are fresh and vigorous, and that they quickly excite fermentation in each new addition of the mixed straw and dung, and act to destroy many seeds of weeds, also, which become involved in the process of decomposition. Sulphuretted hydrogen, sulphides, and doubtless other products of reduction, are formed in such manure through the decay of the organic matters, much as they are formed beneath the surface soil of a stagnant marsh; and it is plain that the fermentation is not of a kind either to cause ammonia to be evolved or nitrates to be formed.

Moreover, in view of the well-known fact that many of the bacteria which take part in the production of sulphuretted hydrogen, during the putrefaction of albuminous matters, cannot themselves support the presence of any large proportion of this substance, it is to be presumed that the quick fermentation of the newly added straw and dung, at the top of the heap, must soon be checked when sulphides accumulate in it. It is not improbable that at the middle of an old heap of such manure there may be but little fermentation of any kind and hardly any waste of material.

This putrid manure is of excellent quality. It is highly esteemed on the Continent of Europe, where it has long been customary to prepare it. When forked out it emits a highly offensive odor, due in some part to the presence of ammonium sulphide which has been formed by the reduction of sulphates in the manure during the process of fermentation. Boussingault has remarked of this kind of manure that he could always tell, by the odor of sulphides, when farm-manure had been properly prepared. In his opinion, these products of reduction can do no harm to vegetation, because they change rapidly to sulphates as soon as the manure has been spread upon the land. But an observer in Holstein has recently insisted that substances injurious to plants do exist in the putrid manure from deep pits, and he urges that it should on this account be spread and left to lie upon the land for 3 or 4 weeks before the time of sowing or planting. One advantage to be credited to manure that has rotted in the deep pits is that some of the seeds of weeds which were contained in the litter, as well as those which have passed undigested through the bodies of the animals, may perhaps be destroyed by the long-continued soaking and the putrefactive influences to which such manure has necessarily been subjected.

As regards the liquid which collects in the cisterns above mentioned, it is notorious that the quality of it is apt to deteriorate rapidly in these receptacles; and it is plain why it should do so, for the nitrogenous components of urine, viz. urea, uric acid, and hippuric acid, are precisely those constituents of animal secretions which decompose the first and the easiest. The nitrogenous matters in dung proper are far less prone to decomposition.

These cisterns, it may be said in passing, are hardly to be commended for our American conditions unless indeed the farmer is a gardener also. The mere farmer would probably find the cost of building and using such cisterns to be larger than the gain from them.

Amount of Litter needed.

The statements of practical men vary widely as to the number of pounds of bedding required daily by neat cattle. In fact the amount needed will necessarily vary accordingly as the food is more or less watery, and more or less highly nitrogenized. Inasmuch as the chief function of the kidneys is to remove waste nitrogenous matters which have been formed within the bodies of animals, it is but natural that the formation of a larger quantity of urea within the animal should increase the flow of urine. Urea is in fact known to be a powerful diuretic agent, when administered as such.

It is evident enough, for that matter, that vastly more litter will be needed by cattle fed with distillery slop — which is at once very watery and highly nitrogenous — than would be sufficient for animals fed upon hay and grain. The old German authorities speak of 8, 9, and 10 lb. of straw for each cow or ox, and few of them recommend so little as 5 lb. in summer and 7 lb. in winter. Heiden has suggested, as a general rule, that an amount of litter equal to one-third the weight of the dry matter in the fodder actually eaten will be sufficient.

Absorptive Power of Straw, etc.

Some experiments may here be cited which were made by Heiden to determine the power of straw to absorb and hold water. Small, compact, weighed bundles of the straws — which contained respectively in the air-dried condition 13.4 %, 13.3 %, 14.8 %, and 15.1 % of moisture — were sunk in water so as to be completely covered. After the lapse of 24 hours, they were taken from the water and set standing in an upright position for half an hour, and they were afterwards left lying for an hour and a half, in order that the excess of water might drain off from them. They were then weighed, and again at intervals, after time had been allowed for some of the water to evaporate. The results of these trials are given in the table: —

	Wheat Straw. %	Rye Straw. %	Oat Straw. %	Pea Straw. %
Water absorbed in 24 hours	225.8	241.4	213.6	280.9
Water evaporated from the wet straw				
In 2 hours	12.6	11.0	5.0	8.4
Next 2 "	5.8	3.6	4.3	12.7
" 16 "	18.9	35.4	14.5	32.3
" 4 "	6.3	2.2	3.8	8.7
" 4 "	1.1	3.3	2.9	7.5
" 16 "	10.5	12.2	9.5	22.6
In the 44 hours	55.0	67.7	40.0	92.2
Water retained after 44 hours	170.8	173.7	173.6	188.7

Another bundle of wheat straw, on being left to soak for 48 hours, instead of 24, took up nearly 22 % more water. That is to say, in the course of 48 hours, the straw absorbed 247.6 % of water, of which amount 18.7 % were given off during the first 6 hours, and 28 % during the next 18 hours, or 46.7 % in 24 hours; so that 200.9 % of water was still retained by the straw even after 24 hours' exposure to the air.

Autumn leaves as raked from woodland can absorb considerably more water than straw, though they absorb it in a different way and are generally inferior to straw for bedding animals, unless indeed they are used in conjunction with straw, i. e. as a layer beneath it. According to Krutzsche, beech-leaves can absorb 442 % of water, pine-needles 309 %, and spruce-needles 221 %.

Breitenlohner also has experimented, though much less carefully than Heiden, to test the absorptive power of different kinds of litter. He left the materials to soak for a week with a given weight of dung-liquor. The straws were cut into short lengths, and so were the evergreen boughs and the heath-litter. The leaf-rakings were dry enough to be somewhat crumbly, and the peats were reduced to coarse powder. Most of the materials were more or less air-dried. The results of these trials are given in the following table:—

	Moisture in the Litter expelled at 212°. %	1,000 lb. of the Litter absorbs Pounds of Dung-Liquor.	Wt. of Liquor absorbed, if that taken by the Fir-Twigs = 100.
Rye-straw	8.0	3,000	1,200
Straw of horse-beans . . .	10.3	3,300	1,320
Sawdust	6.6	3,571	1,428
Heath-litter (including moss)	5.7	3,083	1,233
Leaf-rakings	5.1	4,330	1,732
Spent tan-bark	5.6	2,150	860
Fir-twigs	61.2	250	100
Spruce-twigs	54.2	357	143
Peat	10.5	4,483	1,793
Moor-earth	4.9	550	220

It will be noticed that, weight for weight, the peat and the wood-rakings absorbed more liquor than any of the other kinds of litter, and that sawdust stands near them, while rye-straw is somewhat inferior, and the evergreen twigs are least absorptive of all.

It was observed in special trials, that the moor-earth in particular, and the peat to some extent, "fixed" a part of the soluble constituents of the dung-liquor in such wise that those portions of liquid which were not taken up were found to be weaker than the original liquor; whereas the excess of liquor that drained away from the straws, etc., contained a larger amount of matters in solution than the original liquor had contained.

In experiments made by the Omnibus Co. at Paris, samples of the materials were left to soak under water for 5 days; the excess of water was allowed to drain away and the amount of water that remained adhering to the litter was determined by weighing. It appeared that one kilogram of straw had absorbed 4 kilos. of water, one kilo. of sawdust 5 kilos. of water, and one kilo. of peat-moss nearly 8 kilos. of water.

Of 12 varieties of peat examined by Nessler, the power to absorb water ranged from 200 to 800 %, while the absorptive power of the straw of summer rye was 315 %. These peats absorbed from 1.37 % to 2.53 % of ammonia, also, while the rye-straw absorbed only 0.26 %.

Fleischer found, on comparing immature peats, consisting on the one hand of the fibrous remains of reeds, and on the other of partially decomposed mosses, that 1,000 parts of either of them (containing already 20 % of moisture) absorbed from 6,300 to

9,300 parts of water, and from 13 to 17 parts of ammonium carbonate. But the fibrous peats from reeds were more valuable than those from moss, since 1,000 parts of the dry material contained from 22 to 29 parts of nitrogen and from 17 to 31 parts of lime, while 1,000 parts of the mossy peat contained no more than 9 parts of nitrogen and 2 parts of lime. Both kinds contained about half a pound of phosphoric acid in 1,000 lb. of the dry peat.

Petermann, also, has determined the absorptive power of several kinds of litter, as stated in the following table: —

100 kilo. of	wheat-straw	absorb		254	litres of water.
" "	fern	" "		212	" " "
" "	heath	" "		190	" " "
" "	woad-waxen (genista)			111	" " "
" "	rye-straw		according to Fleischer	389	" " "
" "	fibrous peat			895	" " "
" "	"		(according to Wolff)	7 to 900	" " "

Wollny, with the view of comparing equal volumes of different kinds of litter — instead of equal weights — packed the materials tightly into cubic tin vessels of 8 litres capacity, which he sunk in water so that the surface of the litter should be completely covered with the liquid. It was found that ten days were needed for the complete saturation of the materials. He operated upon wood-rakings, peat-slack, loam, and straws, all in the air-dried condition, as used for bedding animals, and found that of these things peat had the largest and sand the least capacity for absorbing water. Between these extremes, the other matters stood in the following order: 1, peat; 2, loam; 3, moss, oak and beech leaves; 4, pea-straw; 5, rye-straw; 6, pine-needles; 7, spruce-needles; 8, quartz sand. That is to say, moss, and oak or beech leaves exhibited very nearly equal powers of absorption; either of them could drink in about half as much water as peat. Needles of evergreen trees absorbed less than the leaves of hardwood trees. Pea-straw absorbed more than rye-straw, but both the straws stood between oak-leaves and spruce-needles. When it was saturated, the loam held more water than wood-rakings. As regards the loss of water from these substances by evaporation, it appeared that much larger amounts went off in a given time from peat and loam and sand than from the wood-rakings. Among the organized matters, moss exhibited the largest capacity for evaporating water; then came the straws and needles, and, finally, the leaves, which lost less water than any of the other materials.

Ramann and Kalitsch have experimented with wood-shavings of various kinds, as to their value as litter for horses and cattle. Shavings from soft woods were found to have a larger capacity for absorbing water than rye-straw, though a smaller capacity than peat-moss. Hardwood shavings absorbed barely as much water as the straw. In general, the shavings were much cleaner than peat-moss (described in the next chapter). When saturated with liquid manure, shavings of fir, pine and alder decomposed about as rapidly as straw, and those of birch and beech somewhat less rapidly, while peat-moss decomposed much more slowly. It was observed that the shavings had better be from 0.8 to 1.25 inch wide, otherwise they are apt to become entangled in the hoofs of the animals.

Relation of Litter to Food.

It will be noticed that the practical rules given on previous pages apply primarily to grain-growing countries, where straw is abundant, and the conversion of it to manure a desideratum. In New England, on the contrary, it might often be well to use the least possible quantity of bedding, or even none at all in some instances.

For bedding horses, German writers hold that from 4 to 6 lb. of straw are needed daily, and there can be little question that in this case the comfort of the animals is the point first to be considered; though Heiden has argued, even for horses, that the chief purpose of the bedding is completely to absorb the liquid portions of the excrement. Starting from this assumption, he urges that the true way of determining how much bedding to use, will be to consider the character of the food, and so employ more or less straw, according as the food is more or less watery. In the case of horses, he thinks no great error will be made if the amount of straw used for bedding is equal to ¼ the weight of the food taken in its natural condition, or equal to ⅓ the weight of the dry matter of the fodder.

It is more important for horses, however, than for most other animals, that they should be abundantly bedded by night, in order that they may rest comfortably; and that their stalls should be cleaned out thoroughly and often, care being taken to remove, as completely as may be possible, the urine and the straw moist with urine. It is important both to avoid the fumes of ammonia that are generated by the putrefaction of urine, and to hold in check the multiplication of various microscopic organisms, hurtful to the hoofs of the animals, which are apt to thrive in putrid litter.

Practical Methods of Preserving Manure.

The old Roman writers on agriculture recommended that the dung-heap should be kept in the open air, in a spot deep sunk and well adapted to receive moisture, and that it should be covered with straw, that it may not be dried up by the sun. In a similar sense, a recent French writer has laid down rules for the preservation of manure, in the following terms: The dung-heap should be shielded from sun and excessive rain. The fermentation of the heap should be moderated by means of admixtures of loam or some similar material. The heap should be kept moderately moist. Fresh dung should not be mixed with old.

So far as the mere preservation of the manure is concerned, it would be hard to improve upon the practice of certain grain-growing countries, such, for example, as Upper Lusatia, one of the provinces of Saxony, where the dung and litter are allowed to accumulate in thick layers in the stalls, directly beneath the cattle, and in contact with their bodies. The animals are bedded heavily with straw two or three times a day, and the mixture of straw and dung beneath them is pushed forward and made level as often as may be necessary for their comfort. The feeding-troughs are made to slip on the stanchions, and they are elevated as often as may be requisite. The mixture of dung and straw becomes very firmly compacted by the weight of the cattle, and, in the rather cool countries where the system is practised, the dung is maintained in a highly favorable condition of moisture.

The small amount of air that can gain access to the interior of the mass, and the even temperature maintained there, seem to be favorable to the proper fermentation of the manure. At all events, it has been thoroughly proved that such manure is more powerful than that thrown out and left to ferment in heaps in the ordinary way. The method is highly esteemed in the places where it is practised, which are, for that matter, some of the finest farming regions in the world. It is no uncommon thing to see a stable so arranged that the impacted manure may come to be 4 feet or more high, — even 7 feet have been noticed, — and extremely hard and firmly compressed before there is any need of bringing in the carts to remove it. It is carried directly to the fields, where it is spread immediately, and ploughed under in due course.

Manifestly, the stable has to be high-studded: "It should be at least 17 feet high," says one writer, and some kind of a slope must be provided for the cattle to walk down in case they are ever to descend from the bed of manure. At the start, an outlet has to be provided for the excess of urine, since not until after several weeks have elapsed is the whole of the urine retained by the bed of strawy manure. Subsequently all the urine is absorbed and held by the straw, and it is accounted one great merit of the system that more straw can be made into manure by means of it than in any other way.

Several cow-stables thus arranged which I have myself visited had no unpleasant odor, and it is maintained by the people who practise this method that the health of their cattle does not suffer. It is hard to understand, however, how the hoofs of the animals can always escape the diseases that are apt to be caused by certain microdemes which appear to harbor in fermenting dung; and no man can tell without trial how well the system would answer for dairy farms in this country, i. e. in the warmer parts of it. Doubtless it would serve well enough, however, in the case of fatting cattle.

The practice now in question is a very old one. It applies to the preservation of moist cow-dung and the urine of cows. It provides for the thorough absorption of the urine by straw, for the complete admixing of straw and dung, and for the slow, regular fermentation of this mixture. Meanwhile, all the manure is housed and completely protected from the weather. Horsky, on putting in practice this method on an estate in Bohemia, was surprised at the great increase in the amount of manure produced. He says that from a given amount of fodder and straw he got more than 100 % more manure than had been obtained before. He found, however, that for bedding the animals half as much again straw was expended as had been used previously. In general, it may be said that the process strongly enforces the advantages to be gained by allowing stable-manure to ferment slowly. It capitally illustrates the maxim that manure seldom suffers much loss so long as it is kept moist and firmly trodden.

A system analogous to the foregoing is said to prevail in some parts of Belgium, where the manure, though left in the stable, is pushed into a great trough or depression, behind the standing room of the animals, where it is much trampled upon. So too, in England, oxen are sometimes fattened in box-stalls provided with movable cribs, so arranged that all the manure and litter are left to accumulate under the animal during some 5 or 6 months.

Several analyses of manure which had been suffered to lie under the animals as above described have been given in the table of analyses on page 239. It may here be said that, in addition to the chemical analysis, Emmerling subjected samples of manure from a deep stall and from a dung-heap to elutriation with water in such manner that each of the samples was divided into 3 portions, viz. into strawy matter, fine insoluble matter, and matters soluble in water. His results are given in the following table.

One thousand pounds of the fresh manure contained:—

FROM THE DEEP STALL.

	Strawy Matters.	Fine Insoluble.	Soluble in Water.	Total.
Dry matter	148	60	20	228
Ashes	6	11	10	27
Phosphoric acid	0.37	0.91	0.14	1.42
Potash	0.08	0.90	4.69	5.67
Nitrogen in organic matters	0.88	0.67	1.90	3.45
Nitrogen in ammonia	...	...	0.66	0.66
Total nitrogen	...	...	...	4.11
FROM THE DUNG-HEAP.				
Dry matter	115	52	18	185
Ashes	6	11	8	25
Phosphoric acid	0.42	0.52	0.44	1.38
Potash	0.13	0.50	4.11	4.74
Nitrogen in organic matters	0.70	0.99	1.18	2.87
Nitrogen in ammonia	...	...	0.29	0.29
Total nitrogen	...	...	...	3.16

The straw in the manure from the deep stall appears to have been less completely decomposed than that in the dung-heap, a result which points to the similarity of such dung to ensilage. No nitrates could be detected. But it is noticeable, not only that there is more nitrogen in the manure from the deep stall, but that this manure contains more soluble nitrogen, more ammonia, and a larger amount of soluble organic nitrogen compounds. Possibly some of the phosphoric acid in the deep stall had passed into the form of the insoluble double phosphate of magnesia and ammonia.

Fermentations are caused by Micro-organisms.

It is now known that the fermentations which occur in dung-heaps are due to the presence of various microscopic organisms analogous to the "yeast" which, as every one knows, causes sugar to ferment, and to break up into alcohol and carbonic acid. As long ago as 1695, Leeuwenhoek detected the presence of microscopic organisms in dung, though the significance of this capital observation was not fully recognized until recently. Of late years, the old observation has been verified by numberless observers, and the paramount importance of the micro-organisms is clearly seen. It can now readily be understood how it is that loose dung may undergo active and violent fermentation, such as would be impossible in case the materials were firmly compacted or mixed with a considerable amount of earth or other inert matter, and especially if they were packed in a silo or drenched in a pit. It is known too that the alkalinity of decaying manure is a condition favorable for the development of the micro-organisms which cause fermentation, and that the fermentation of manure could readily be checked by means of acids.

Some Kinds of Ferments need Air.

Pasteur has shown that two distinct classes of microscopic organisms are concerned in fermentations. The members of one of these classes are active only in presence of air or free oxygen gas, while those of the other class require neither air nor free oxygen for their support, since they can obtain a sufficiency of this particular kind of food by taking it from organic matters that contain oxygen as an essential constituent. Ferments of the kinds that need air have been designated as *aerobic*, and those which act in the absence of air are called *anaerobic*.

The anaerobic ferments — viz. those which can live without air — act to break up pre-existing compounds into new and simpler forms, and when this work has been accomplished their activity must cease. But in case the fermenting substance is exposed to air, decay will go on indefinitely. In other words aerobic ferments will live and thrive upon it continually, even upon the disorganized materials which have been exhausted, so to say, by the anaerobic ferments. Thus it happens, when the conditions are such that the external air cannot gain access to manure, that the internal or anaerobic fermentation of the constituents of the manure may speedily run its course and wellnigh cease.

It is to be presumed also that the chemical products generated during the anaerobic fermentation must soon check the activity of the micro-organisms which occasioned it, and that the carbonic acid, which cannot readily escape from the mass of manure, must soon permeate every part of it, and help to exclude air, and so tend to repel the aerobic ferments, even if this carbonic acid may not act directly to destroy these ferments when present.

The power of carbonic acid to check certain forms of decay was clearly recognized long ago, and strongly insisted upon. The distinguished chemist and physician, Macbride, writing in 1764, intimates that he has found "very strong reasons for believing that carbonic acid is the grand preserver of animal fluids from putrefaction." This belief he proceeded to justify by several well considered experiments. He dwells even on the power of carbonic acid to "restore sweetness," an effect which, as we now know, must depend on the destruction, by the carbonic acid, of some of the microdemes which cause decay. One of Macbride's experiments was to hang a bit of putrid mutton, "cut thin, so that the vapor may have power to pervade it," in the mouth of a vessel in which molasses wash was fermenting, in such manner that the meat should not touch the liquid, but be continually enveloped with the gas developed from it by the fermentation. After having been thus left over night, the meat was found next morning "plumped up, sweet, and firm."

So, too, John Davy remarked that "the products of putrefaction, viz. carbonic acid and carbonate of ammonia, exert [to a certain extent] an antiputrescent action." Fraenkel has found, in fact, that very few micro-organisms prosper in an atmosphere of carbonic acid, though among the exceptions beer-yeast and the lactic ferment are conspicuous. He found that the development of most micro-organisms is decidedly hindered by the presence of carbonic acid. But it has often been remarked how little the activity of beer-yeast is impaired by the presence of carbonic acid. Thus, Lindet caused the carbonic acid evolved during fermentation, by means of yeast, to be retained in the vessels under pressures of 20, 200, 430 and 600 mm. of mercury, and observed no differences, either in the amount of alcohol produced or in the weight of yeast obtained.

Acids are Inimical to most Micro-organisms.

Pringle observed, as long ago as 1750, the fact, of a somewhat different order from the foregoing, that an increase of acidity may check putrefaction. He says: "When farinaceous vegetables were examined, viz. white bread in infusion, and decoctions of flour, barley, and oatmeal, they did not at all retard putrefaction (of flesh) at first; but after it was somewhat advanced, they checked it by turning sour. . . . By a long digestion, the acidity became considerable, which by conquering the putrescency of the flesh," etc.

For this matter, the preservative power of acids, such as vinegar, is well known, and familiarly made use of in domestic economy. In this sense, true superphosphate of lime is capable of preserving dung and urine. Krause found that so little as one per cent of a good superphosphate was an excellent preservative of manure that was shielded from rain. Fresh cow's urine, mixed with the superphosphate, lost no nitrogen whatsoever.

Maercker has shown that even the fermentation of sugar, by means of yeast, is arrested by the presence of 3 or 4 % of lactic acid, 0.5 % of acetic acid, 0.2 % of formic acid, 0.1 % of either butyric or propionic acids, and by traces of caproic acid. Generally speaking, microbes are particularly sensitive to the influence of dilute mineral acids. Most of them are paralyzed in the presence of no more than half of one per cent of one of these acids. It is true, also, that bacteria develop best in substances which are neutral or slightly alkaline, though their activity is not wholly checked by the presence of minute quantities of the organic acids that are developed by fermentation. A small amount of acidity, due to this cause, simply diminishes the activity of the ferment, without stopping it altogether. But it is noticed, in the case of organic matters decaying in the air — when the acidity of the materials has become sufficiently marked to hinder the action of the bacteria — that the conditions are now favorable for the growth of moulds, which speedily take possession of the field, and act to consume the products formed during the fermentations which the bacteria had induced. Unlike the micro-organisms of ordinary putrefaction, moulds grow well on substances which are noticeably acid, as is seen familiarly in the decay of sour fruits. Practically, it is found that putrescent bodies exhibit an alkaline reaction, and that a certain degree of alkalinity is favorable for putrefaction.

When a piece of firm, fresh meat — which is naturally very slightly acid — is left exposed to the air, at the ordinary temperature, and to the attacks of the germs and micro-organisms which the air contains, it will be noticed, after a while, that the meat softens somewhat, in consequence of the action of the lactic and the butyric ferments, and acquires a peculiar flavor, unlike that of fresh meat. At this stage, the flesh exhibits an acid reaction, due to the presence of the acids above named. Even when this acid fermentation is somewhat advanced, the odor of the meat will be butyric rather than putrid.

In due course, the acid ferments are succeeded by others, with the result that certain albuminoid constituents of the meat are decomposed, with formation of ammonia, which neutralizes the lactic and butyric acids, and imparts a decided alkaline reaction to the flesh. Then it is that true putrefaction sets in, with rapid disorganization of the constituents of the flesh, and evolution of highly offensive odors. Fish decays much more rapidly than flesh, because it is alkaline from the beginning, and is invaded at once by the bacteria of putrefaction, without undergoing the lactic fermentation. (Garnier.)

Fermentation of Manure.

For exciting the hot, active putrefaction of manure, the presence of a certain amount of air seems to be needed at first, while for slow, regular fermentations, such as may occur in impacted manure, for example, little if any air is necessary, since, as has been said, the organisms which cause such fermentations are able to procure oxygen enough for their support from that which is held in actual combination by the organic matters in the manure.

It is a familiar fact that fermentations due to the presence of microbes run a certain course, and attain to a maximum of activity, and then slacken off and finally come to a standstill. Sometimes, indeed, it is found, when the fermentation has ceased, that the bacteria which abounded in the fermenting materials have all perished. This checking or cessation of fermentation may depend, in some cases, upon the destruction or using up of materials upon which the micro-organisms fed, and in this event the organisms are simply starved out; but in other cases the cessation is known to be due to the formation of acids and other products of decomposition, in presence of which the microbes cannot live. In this case, the organisms are crippled or poisoned, and so hindered from inducing fermentation, even when an abundance of food still remains at their disposal. It is true, also, even of many of the anaerobic ferments, that they respire best when not wholly excluded from contact with the air. That is to say, the presence of some traces of air — at the least, occasionally — seems to be helpful for maintaining the fermentation in full vigor. Thus, in the case of ordinary yeast, which has been left to act upon sugar-water for a considerable time out of contact with the air, it is noticed that the fermentation ceases to be vigorous, and, on examining the yeast globules, they are seen to be not young and active, but old and degenerate. Meanwhile, the liquid has become completely saturated with carbonic acid. Under these conditions, renewed activity of the fermentation may be incited by causing a few bubbles of oxygen gas or of air to pass through the liquor. Practically, in the fermentation of wine, or the like, it is customary not to exclude air absolutely, though care is always taken that very little air shall gain access to the fermenting liquid.

In proof of the significance of micro-organisms for exciting fermentations, Pasteur has shown that the air in a closed flask, partially filled with urine, may be deprived of all its oxygen in the course of a few days through formation of carbonic acid by the action of organisms whose germs were floating in that air. But on charging a flask of urine with air that has been ignited to destroy the germs naturally contained in it, the liquid will remain almost without change for years, and comparatively little of the oxygen in the flask will be converted to carbonic acid.

In one case, Pasteur found that the air which had thus been left in contact with urine for three years contained 11½ % of oxygen, 11½ % of carbonic acid, and 77 % of nitrogen. He found that blood also, as well as urine, could readily be kept, in contact with air, undecomposed, if only pains were taken to destroy the germs in the air and prevent the access of others.

In another experiment, oak sawdust, that had been boiled with water, was left in contact, at 86° F., with air that had been ignited. But after a month had elapsed, this air was found to contain 16¼ % of oxygen, 2⅓ % of carbonic acid, and 81½ % of nitrogen. Whereas, on repeating the experiment under ordinary conditions, i. e., with unignited air and unboiled sawdust, a large amount of oxygen was speedily removed from the air, and carbonic acid formed.

All putrescible matters, such as dung and urine, milk, blood and flesh may be kept fresh for any length of time — as is done in the ordinary process (Appert's) of canning meat and vegetables — by first heating the materials, to destroy whatever germs may have fallen upon them, and afterwards taking care to shield them from coming in contact with new germs. In so far as concerns the question of their fermenting or putrefying, it is not essential that the matters to be preserved should be sealed up so that air shall be excluded; they could still be kept — though much less conveniently, and probably with some loss of flavor — by arranging matters in such wise that air could freely come to them after it had either been calcined, or most carefully filtered so that all germs originally contained in it should be destroyed or arrested. When this experiment is performed, it is easy to excite fermentation at any moment by throwing in a little dust collected from the air, such as may be obtained by straining a considerable quantity of air through a tuft of cotton.

Fermentations differ according to Circumstances.

It may be laid down as a rule, that the fermentations of manure will vary materially according as more or less air has access to the heaps, and as more or less water is contained in them; or, in other words, according as circumstances favor the growth of one or another kind of micro-organism. It is with manures somewhat as it is with soils, only that the fermentations of the manures are more evident and pronounced. In loose heaps of horse-manure, to the interior of which air has tolerably free access, aerobic ferments often display great activity, a great deal of organic matter is destroyed and much carbonic acid evolved, while no little heat is developed. It may happen indeed under favorable conditions that heat enough is set free to kill the organisms which have caused the fermentation. To illustrate this matter Guyon packed some manure in a wooden box, of the capacity of a cubic metre, and having closed the box tightly in order to exclude air, he noticed that the temperature of the manure hardly rose to 59° F., while the thermometer was seen to rise to 162° F. in another equal mass of similar manure that had been packed in an open-work basket made of wire gauze, so that air could have free access to it. Even in dry, porous heaps of compost there may be rapid wasting of the carbonaceous matters by processes of oxidation, as will be explained under Composts.

On the other hand, when air is excluded from manure the action of anaerobic micro-organisms causes such fermentations as produce marsh-gas (CH_4), as well as carbonic acid, if the manure is alkaline, as it should be and usually is; or hydrogen and carbonic acid if the manure is acid. Very much less heat is developed by these anaerobic fermentations than by those which occur in the presence of air. Meanwhile small quantities of various acids such as butyric and lactic acids may be formed.

Ordinarily several kinds of fermentations appear to progress simultaneously, or at the least to follow one another rapidly, and it is true that purely chemical processes of oxidation often occur at the same time with the fermentations proper, and that they may succeed them also. Indeed, it is not to be supposed that there is usually any sharp line of demarcation between the two kinds of oxidation, but that the one may gradually shade into the other. Thus, when the heat caused by ferment action in a manure-heap has become high enough to excite purely chemical oxidations, the latter will naturally occur simultaneously with the ferment action, and subsequently when the heat has become great enough to destroy the ferment organisms so close an approximation to the kindling temperature of the organic matter will have been reached that slow chemical combustion will go forward by itself, often for a considerable period of time. Under peculiarly favorable conditions, it may even happen that the litter in the manure-heap may take fire spontaneously, and cases in which this result has been reached have sometimes been noticed, though rarely.

In order to study the matter, Schloesing selected a number of samples, each of one or two pounds weight, from a great heap of manure which had been well forked over and thoroughly mixed, and having placed these samples in appropriate vessels, he sterilized all of them by maintaining the vessels with their contents at a temperature of 221° F. for an hour. A certain number of the samples were then "seeded," by adding to them some non-sterilized dung, and measured quantities of filtered air were made to flow over all the samples, the rate of flow being regulated so that the outgoing air should always contain an excess of oxygen and at least 1–2 % of carbonic acid. The amount of carbonic acid produced was determined daily. From the figures in the tables, in which the quantities of carbonic acid evolved by the seeded and by the sterilized samples are compared, some idea may be gained as to how much of the carbonic acid was produced by ferment action, and how much by mere chemical oxidation, for the assumption is that on subtracting the carbonic acid of the sterilized samples from that of the seeded, the difference will give an approximation to the amount produced by ferment action.

From horse-manure with 75% water.	At 150° F., there was evolved in 24 hours by each kilo. of dry manure, grm. of CO_2.	
	Sterilized.	Seeded.
2d day	. .	33.8
3d "	1.1	26.0
4th "	0.9	22.2
5th "	1.3	18.6

From horse-manure with 71 % water.	At 175° F. there was evolved in 24 hours by each kilo. of dry manure, grm. of CO_2.	
	Sterilized.	Seeded.
1st day	2.8	3.7
2d "	2.3	2.1
4th "	1.8	1.9
5th "	1.4	1.5

From horse-manure with 76.2% water.	At 162.5° F.	
2d day	2.3	9.8
3d "	2.9	14.6
4th "	1.9	29.8
6th "	1.4	20.7
15th "	1.4	8.3

Ditto.	At 163° (newly sterilized.)	
2d day	1.3	1.4
4th "	1.1	5.3
5th "	0.9	5.9
7th "	0.8	5.2
28th "	0.8	2.0

Ditto.	At 178° F.	
2d day	3.9	4.1
3d "	2.8	2.8
4th "	2.6	2.4
6th "	2.1	2.4
15th "	1.4	1.4

It is evident from these results that the ferment organisms could not live at 175° F., while at 163° they exhibited some activity, and still more at 162.5°. The trials at 175° and at 178° show that the merely chemical oxidation in a dung-heap may be of considerable moment. In no instance was any inflammable gas detected in the outgoing air.

In other experiments, the action of anaerobic ferments was tested by causing nitrogen gas to flow through the apparatus, instead of air. The results of these trials are given in the following table. The horse-manure employed contained 60 % of water, and the figures represent the number of litres and fractions of litres of gas which were given off in 24 hours from one kilo. of the manure: —

	Gas given off at 126° F.						Gas given off at 151° F.					
	Sterilized.			Seeded.			Sterilized.			Seeded.		
	CO_2	CH_4	H	CO_2	CH_4	H	CO_2	CH_4	H	CO_2	CH_4	H
5th day	0.07	0	0.01	1.33	0.11	0	0.21	0	0.04	1.25	0	0.04
12th "	0.19	0	0.03	1.96	1.81	0	0.52	0	0.20	0.63	0	0.34
17th "	0.16	0	0.02	1.68	1.61	0	0.40	0	0.16	0.42	0	0.17

From these trials, and from others made with cow-dung, it appeared that the marsh-gas fermentation no longer occurred at 151° F. But at 126° F. this form of fermentation was active, and both the decomposition of the organic matter and the evolution of carbonaceous gases was much more rapid in presence of the anaerobic micro-organisms than in the sterilized dung. It will be noticed that, while the oxidation due to purely chemical action was much more marked at 151° than at 126°, the evolution of carbonic acid was not, in any instance, so abundant in the absence of the ferment as in its presence. In no instance was any free nitrogen gas evolved from the fermenting dung. On the contrary, all the nitrogen of the organic matter that was decomposed by the ferment was evolved in the form of ammonia.

In some cases, the so-called lactic fermentation occurs, which is accompanied with the formation of lactic acid, while at other times butyric acid and other kinds of acids are formed. The presence of butyric acid has often been detected in fermenting manures, in decaying fruit, flesh, and pulse, as well as in the soil, and there are reasons for believing that putrefaction, properly so called, may often be little more than a butyric fermentation. But Pasteur has shown that the organisms which cause the butyric fermentation, far from needing air, can live and multiply in organic matters, even when no trace of free oxygen is present. Indeed, air destroys these organisms, and the admission of it to materials upon which they are at work will arrest the fermentation.

Another kind of fermentation occurs when fresh urine comes in contact with putrid urine, the urea in the fresh urine being quickly changed to carbonate of ammonia by the action of a peculiar organism with which the putrid urine has become charged: —

$$CH_4N_2O + 2\,H_2O = (NH_4)_2\,CO_3.$$

In consonance with the foregoing statements, Dehérain has noticed two distinct fermentations in heaps of manure, viz., an aerobic fermentation, as a result of which the temperature may rise to 150 or 160° F., and an anaerobic fermentation which occurs at temperatures of 85 or 95°. The two fermentations are distinguished by the fact that different and characteristic gases are found among the products of the decomposition of the manure. A heap of loose manure, as well as the hot upper layers of an ordinary heap, to which the oxygen of the air has access, will be found to contain an aerobic ferment whose activity gives rise to the evolution of carbonic acid; while at the centre of a compact heap, and in its lower layers, where the anaerobic ferment is at work, marsh-gas (CH_4) is found, as well as carbonic acid.

This marsh-gas fermentation (anaerobic) may readily be excited artificially by moistening some paper, or cotton, or straw, in a bottle, with weak solutions of carbonate of ammonia and carbonate of potash, together with a little phosphate of ammonia, and adding a few drops of barnyard-liquor (which contains the ferment). On maintaining the bottle and its contents for some weeks at a temperature of 104° F., the fermentation will run its course with decomposition of the cellulose of the paper, etc., while equal volumes of marsh-gas and of carbonic acid are set free. It is in this way that the cellulose in the straw of a manure-heap is broken up, and the coherence of the straw destroyed.

Manure may spoil in Loose Heaps.

The system of compacting cow-manure, just now described, offers a strong contrast to the common habit of leaving horse-manure to spoil itself by rapid fermentation in dry, loose heaps, and indicates the absurdity of this habit. Horse-manure is not only dry naturally, but it is usually highly nitrogenous, because horses are fed habitually with an abundant ration of grain. Consequently, it decomposes with great rapidity and considerable losses of nitrogen may ensue, — chiefly in the form of gaseous ammonium carbonate. Boussingault observed of a lot of horse-manure, the dry matter of which, when in the fresh condition, contained 2.7 % of nitrogen, that it lost nearly two-thirds of its nitrogen in the process of decay. After complete decomposition, the dry matter of this manure contained only 1 % of nitrogen.

A conspicuous feature in heaps of loose, dry horse-manure is the mycelium of a fungus — made evident by numberless white threads in the manure, and by the white dust which rises in clouds when such manure is stirred. This fungus penetrates every part of the heap, to consume the carbonaceous and nitrogenous matters, and soon changes the manure to the condition known as "fire-fanged." It is to be presumed, of course, that the nitrogen in the substance of the fungus is less active as a fertilizer than that in the original manure. By mixing peat or loam with fresh horse-manure, the growth of the fungus may be prevented, or at the least checked, and the manure be kept in much better condition.

It is to be noticed that the checking of fermentation in this case by the admixture of loam points to the fact that the preservation of manure is far enough from being a purely chemical question. The merit of the loam consists not alone in its "holding" ammonia, as was formerly supposed, but in that it makes the manure-heap a less agreeable feeding-ground for that particular kind of fungus which causes fire-fanging. Still better than mere dilution with loam, the mixture of horse-dung and loam, or of horse-dung and cow-dung, may be kept slightly moist and trodden down compactly, as is in fact sometimes done in this country by means of swine in barn cellars. In the main, however, not half enough attention is given to the care of horse-dung. Many farmers are apt to overlook the fact that, when fresh, it is not infrequently more valuable than cow-dung and they seem to forget that it spoils so easily.

A system of compressing horse-manure into bales, as if it were hay, in order to facilitate its transportation, has occasionally been practised at some of the larger stables in New York City, though very little appears to have been published with regard to the utility of it. An opinion seems to prevail, however, among practical men, that the baled manure has been found useful in field practice. It is probable that this particular product is much drier than the impacted Saxon cow-manure above described.

Another instance of impaction is seen in the case of sheep-manure from stables where the droppings and litter have been left for a long time under the animals, as is usual in many localities. It is very questionable, however, in this case, where the manure is comparatively dry, whether a large part of its most valuable constituents may not have been destroyed by improper fermentations. Nitrification is known to occur, however, in such sheep-manure, and to a very considerable extent.

Pounds of Food eaten indicate Yield of Manure.

The amount of manure produced by animals may readily be computed approximately from the amount of food which they have eaten (or are to eat), and the quantity of straw that is employed for bedding them, though the details of the calculation will necessarily vary slightly for each kind of animal, since the excrements of some species of animals are more watery than those of other species. A thousand pounds live weight of neat cattle, for example, will ordinarily produce a larger number of pounds of manure than would be produced by 1000 lb. live weight of sheep.

Heiden has given several instructive examples of this method of computation. In the case of horses, it appears that some 47.33 % of the dry matter in their food passes out from them in the solid and liquid excrements, and that the percentage of water in these excrements amounts to 77.5 on the average; so that in the total excrement there is about 22.5 % of dry matter. Whence it appears that, from every 100 lb. of dry matter eaten, 210 lb. of fresh manure will be produced,

22.5 : 100 : : 47.33 : 210,

or, for each pound of dry matter in the fodder there is obtained rather more than 2 lb. of manure.

In case the animals were standing all the while quietly in their stalls, the weight in pounds of fresh excrement produced by them would be got by simply multiplying the number of pounds of dry matter in their fodder with the factor 2.1. To the product thus obtained would be added the number of pounds of straw that have been expended in bedding the animals, say 6.5 lb. per diem on the average. But in case the animals are worked, there must be subtracted whatever dung and urine have been dropped outside the stables.

If, for example, it be assumed (with Heiden) that a horse works 260 days of 12 hours each in the course of a year, or 130 whole days, it may be admitted that 235 days have been spent in stall; and by multiplying this number with the daily product of dung, as above obtained, and adding the yearly expenditure of straw, there will be got an approximation to the yearly product of manure. Heiden makes out in this way that a well-fed working horse will produce about 50 lb. of manure a day, or some 6¼ tons in the year, as above stated. Of course, much must depend in each particular instance on the liberality with which straw is used for bedding the animals. Armsby found in a horse-stable where the soiled straw was spread out and dried every day to be used over again — as is the custom in most town and city stables in this country — that the consumption of bedding amounted to almost 7 lb. per horse and per day; while in a stable where fresh straw alone was used, and the soiled bedding was thrown immediately upon the dung-heap, as much as 15 lb. of straw was used per day and per horse.

In the case of cows or other neat cattle, it has been observed that the animals void some 48 % of the dry matter of the food in the liquid and solid excrements, and that the fresh excrements contain on the average 87.5 % of water and 12.5 % of dry matter. But

12.5 : 1 : : 48 : 3.84,

so that in this case we have the factor 3.84 with which to multiply the number of pounds of dry matter in the fodder in order to obtain the number of pounds of fresh excrement. To the product of this multiplication must be added, as before, the straw used for bedding, which for animals kept in stall should amount, according to Heiden, to not far from one-third the weight of the dry matter of the fodder.

Hence, an ox of 1,000 lb. weight, consuming 27 lb. of dry matter per diem, will produce in a day (27 × 3.84) + 9 lb. of manure, i. e. nearly 113 lb. And in a year he will produce some 20 tons. In the same way it may be concluded that young cattle of 500 lb. weight, consuming 16 lb. of dry matter per diem, will produce in a year 12 tons of manure apiece. Where cows are pastured in summer, or where they are kept up of nights without bedding, allowances must of course be made both for the time they are absent from the stable and for the straw that has been saved.

For sheep, it may be assumed that 49.33 % of the dry matter of the food goes into the excrements, and that the fresh excrements contain 73 % of water and 27 % of dry matter. Hence the factor 1.83, which, when multiplied into the dry matter of the fodder, will give the weight of the fresh excrement, for

27 : 1 : : 49.33 : 1.83.

Here again the weight of the straw used for bedding must be added to the product of the multiplication. Thus, a 60 lb. sheep eating 2 lb. of dry matter daily, and bedded with three-fifths of a pound of straw, will produce about three-quarters of a ton of manure in a year. The amount of manure would naturally be less in case the animals were pastured, or bedded only part of the year. For sheep in fold, the daily product of manure may be got by simply multiplying the number of animals by 3.7 (= 2 lb. of dry matter multiplied by 1.83, as before).

Weight of any Heap of Manure.

Naturally enough, the weight of a cubic foot of manure will vary very much according as the manure is more or less wet. As will be seen in the next chapter, Henry Stewart found that fresh horse-manure tightly packed might weigh as much as 64 lb. to the C. F. and that fresh cow-manure, free from litter, similarly packed, weighed 66.5 lb. to the C. F., while S. W. Johnson examined a tolerably fresh (but less moist) sample of horse-manure that weighed no more than 35 lb. to the C. F., and a poor sample of barnyard-manure (from young cattle) that weighed 40 lb. to the C. F. But it is not difficult to estimate the quantity of manure in any given pile or bed if only, after the pile has been measured, pains are taken to pack and weigh a fair sample of the manure in a box, or cart-body, of known dimensions, and to calculate the weight of the whole heap from that of the sample. For example, if from a stable of milch cows, which have been bedded with straw, there has accumulated in the cellar a bed of half-rotted manure 20 feet long, 10 feet wide and 4 feet high, and it is noted that this manure is moist indeed, but not dripping wet, it is not unlikely that the manure may weigh something like 60 lb. to the cubic foot. But if this assumption be true, then the heap 20 × 10 × 4 will contain 800 C. F. (or rather more than 6 cords), and will weigh 800 × 60 = 48,000 lb., or 24 tons.

Well-rotted Manure.

In the light of what is now known as to the chemistry of the subject, and particularly in view of the practicability of supplementing farm-manure nowadays with artificial fertilizers, it is safe to say that most farmers unduly esteem old fermented manure, which has been forked over repeatedly, and has rotted until it has become a soft black mass.

It is essential indeed that manure shall never be applied to a crop in such condition or in such quantity that the crop may be injured by the putrefaction of the manure. It hardly needs to be said that if a large lump of fresh manure were put into the earth of a flower-pot in which a plant was growing, it would be apt to kill the plant. The roots of the plant — far from insinuating themselves into the crevices in the lump of fresh manure or of clasping and clinging to it as they might do if the manure were thoroughly rotted — would be repelled, and those roots which did come into contact with the manure would be apt to become mouldy and rotten through the action of micro-organisms with which the fresh manure is charged. So too, if, in transplanting a tree, the roots were placed immediately upon a mass of fresh manure, the tree would probably die. But it will be noticed that such accidents as these are due to the large quantity of fresh manure which has come in contact with the roots of the plants, and that there can be little if any risk of trouble of this sort in field practice, provided the manure has been applied in suitable quantity and has been thoroughly mixed with the soil before a crop is planted.

On the other hand, there can be no doubt as to the great fertilizing power of fermented dung, nor of the fact that it admits of being distributed more evenly and worked into the soil more thoroughly than long manure. For light land, and for soils inadequately supplied with moisture, well-rotted manure may be vastly better than long manure, because it helps to retain the store of moisture in the soil, instead of working to dissipate it by lightening and opening the land. It is a maxim of English farmers, that short dung or artificial fertilizers should be used for turnips on dry soils. But on low-lying land, and on heavy soils, fresh manure may, on the whole, be preferable. Long fresh manure might safely be ploughed in before winter also, for the use of a spring crop, although wholly improper for application in the spring to light land.

A distinction must be made, of course, between mere cow-dung such as is thrown out from most American barns, and the "stable-manure" of European writers, which is dung (and urine) admixed with much straw or other litter. In general, well-rotted manure will be less apt than fresh dung and urine would be to excite rank growth, such as would cause a grain crop to run to leaf. Many farmers have flattered themselves with the belief that well-rotted manure must, generally speaking, contain fewer seeds of weeds than fresh manure, and there is undoubtedly something of truth in this conception, though, as every one knows, the fact of the matter is that stable-manure, no matter how old, is ordinarily so highly charged with weed-seeds, that there is practically no great difference to be allowed for between fresh and rotted manure, on this account. Meanwhile, it is worthy of remark that no one knows as yet whether fresh manure may not contain a larger proportion than old manure of the spores of the parasitic fungi which do such good service upon the roots of clover and of some other crops. There can, of course, be little doubt that very old manure, when once it is distributed, is one of the best possible breeding-places of those useful organisms which, as is now known, are the moving cause of nitrification; whence it follows that the application of old, thoroughly-rotted dung may be regarded as one exciting cause for fermenting and fertilizing the inert humus which is already in the fields. Yet it is none the less true, that chemists, almost without exception, are in favor of applying dung and urine to the land in the freshest possible state; and that many of the most successful and celebrated among practical agriculturists are entirely of the chemists' opinion.

Fresh urine, in particular, contains those highly important chemical substances, urea, uric acid, and hippuric acid, which are known to be admirable nitrogenous fertilizers, and which we can no longer hope to find in well-rotted manure. The moment any kind of manure begins to ferment, no matter where, it gives off some of its substance in the form of gas; but if the fermentation occurs within the soil, it will be gradual, and the products of decay can be utilized by the neighboring plants. Moreover, fresh manure, in fermenting within the soil, will act upon the soil advantageously in various ways. It will not only play the part of a ferment, and so tend to decompose the inert nitrogen compounds of the humus, but the products of its decomposition will act as disintegrating agents upon the insoluble portions of the soil. There are, in short, many reasons for believing that a larger proportion of the useful constituents of mere dung can be utilized by burying it in the soil when fresh, than if it be left to ferment in heaps. The horse-manure just now alluded to may be cited as a case in point. Everybody admits the efficacy of horse-dung from stables when it is applied to the soil in the fresh unfermented condition, but there are many farmers who justly set no great value on horse-manure from which the goodness has been "burned out," as the term is, in the process of hot fermentation. Then again, there is to be remembered the probability that some of the nitrogen in fermented manures may have passed into the inert, humus-like condition.

Rankness of Fresh Manure.

There are nevertheless several practical considerations which count in favor of using well-rotted manure, especially in case the manure is to be used on grain by itself, and not in conjunction with an artificial fertilizer. Many practical men have urged that fresh manure, even if it does not actually injure the crop to which it is applied, may still tend to the production of stems and leaves, rather than of seeds and fruit. This remark is particularly true of wheat in moist climates. In the words of an English farmer, "There is no crop about which we should be so cautious as about the wheat-crop. If you give a root-crop more help than is necessary, you waste so much money, unless the manure remain in the ground; but if wheat be over-fed, in a wet season it goes down, or in a dry, cold May it is mildewed. . . The better the land, the more the wheat will be mildewed; and the better farmed the land is, the more will the wheat be mildewed."

In Europe, there is a wide-spread belief that, while fresh manure may perhaps be best for forage crops, well-rotted manure or compost is better suited for the production of grain or seeds; and, on this account, in many regions manure is applied by preference to a preparatory crop rather than directly to grain. Cobbett even went so far as to assert as "certainly true, that dung is not the best sort of manure for a garden. It may be mixed with other matter, and if very well-rotted, and almost in an earthy state, it may not be amiss; but if otherwise used, it certainly makes the vegetables coarse and gross compared to what they are when raised with the aid of ashes, lime, chalk, rags, salt and composts. Besides, dung creates innumerable weeds. It brings the seeds of weeds along with it into the garden, unless it has first been worked in a hot-bed, the heat of which destroys the vegetative quality of the seeds."

Even in respect to forage crops, excessive rankness may not be wholly desirable. Thus, German farmers have urged that although clover-fields which have been top-dressed with dung in the autumn may yield an extraordinary increase of crop, such over-dunged clover is not readily eaten (when green) by animals. It is said in Germany that fresh stable-manure makes the flax-plant grow long and stout, but that the fibre is coarse. Hence a preference, in this case also, for land which has been manured beforehand.

As will be seen in the chapter relating to night-soil, the objectionable rankness of fresh manure is particularly well-marked in the case of human excrements. Those nations which most freely use night-soil take special pains to mitigate this rankness by processes of fermentation and of composting. But, manifestly, the rankness of fresh dung and urine could be controlled and utilized by applying the manure in small quantities and supplementing it with artificial fertilizers of kinds appropriate to the crops that are to be grown.

This same fear of the forcing effects of fresh manure has often led farmers to apply it in autumn to land that is not to be sown until the next spring. In the old days of common fields, manure was habitually ploughed into fallow land in the spring or early summer, several months before the time for sowing grain. By soaking into the soil, the soluble constituents of the manure are diluted, as it were, and the material is brought to a condition not unlike that obtained by rotting manure in heaps; though in all probability, the mitigation of the manure may depend in some part on an actual loss of highly useful constituents.

In many fertile, new countries — notably in several of our own Western States — farmers are often put to considerable trouble in throwing away the manure which is produced in their barns and yards. It is customary in those regions to haul out the manure from the farmyard occasionally and dump it into the nearest river or bog-hole, or to leave it to decay in some waste place It is to be presumed that the first settlers in such places were taught by experience that on land already sufficiently charged with good humus, manure may do more harm than good.

Too much Manure is Harmful.

It needs to be understood, of course, that the difference between the action of fresh and rotted manure is one of degree merely. Large dressings of any kind of dung will cause rank growth and be hurtful to some crops, such as grain and many of the grasses. It is a matter of yearly observation, in laying down land to timothy or orchard-grass, that not these grasses but bunches of coarse weeds grow on those parts of the field where heaps of manure have lain; and it is noticeable that these blemishes are particularly conspicuous in cases where the heaps have contained some night-soil. So too, in case a well-established grass-field were to be very heavily top-dressed with manure, the grass would grow close and rank, with soft and tender stems not well-fitted to sustain the great weight of the crop. Such grass might be mown frequently and fed out green, but if it were allowed to stand long enough to be cut for hay it would be apt to lodge and then to rot at the roots.

It is easier, however, to deal with heavy crops of grass in countries where the summers are hot and dry, than it is in regions that are more moist. Thus, Gasparin has said of the South of France that the farmers there are not afraid to cut 4 tons of hay to the acre on their permanent mowing-fields, while at Lille, in Northern France, Kuhlmann regarded 3 tons to the acre as excessive. Some kinds of useful plants, it is true, can bear this rankness of manure, notably hemp, potatoes, Indiancorn and turnips, and it has been said by practical men that it is impossible to over-manure fields on which rape is to be grown, or a mixture of vetches and ray-grass. Chaptal insisted in his day that in Belgium the custom was to employ night-soil in the first year of its decomposition for growing hemp, flax and rape-seed, and to use it in the second year for the cereal grains. On some parts of the fertile plains of Hungary, where "the land will grow wheat year after year without manure, if manured, it must not be for wheat, but for rape or Indian corn, and then (i. e., in the next year) wheat stands up well; but if dressed with dung, it lodges." (Wrightson.) On some of the fenlands of England — cultivated under a four-course rotation of roots, barley, clover, and wheat — the whole of the farmyard-manure was applied to the roots, and sometimes it was supplemented by artificial fertilizers.

In cases where neither roots nor pulse were grown, it was formerly held in England that the manure for wheat should be applied to a bare fallow as early in the summer as possible. An English farmer, writing in 1847 on the management of wheat, remarked that, "The practice of manuring immediately before sowing wheat, though still adhered to in many parts of the country, is objectionable." So, too, as Marshall tells us, in times when the farmers of East Norfolk were accustomed to plough under farmyard-manure in summer upon fallow fields which were subsequently to carry wheat, the practice was to begin to sow the wheat between the 17th and 24th of October, and to continue to sow through November, or even into December. "The reason which the Norfolk husbandmen give for sowing their wheat so late, compared with the practice of other light-land counties, is that their early-sown wheats are liable to be winter-proud, and run too much to straw. . . . Where the soil is good, and the wheat apt to run too much to straw, some few judicious farmers (in the year 1780) set their manure upon the young clover, thereby checking the effect of rankness to the wheat. . . . Land which has previously been heavily dunged for turnips requires no further addition of manure for wheat."

Manufacturers of sugar in Europe long ago recognized the fact that the quality of beet-juice is injured when the beets are fertilized with dung-liquor or with heavy dressings of farmyard-manure applied in the spring. It is said also that the quality of tobacco is injured by manuring the land too heavily, and especially by applying night-soil, or by watering the growing plants with liquid manure, though tobacco is a crop which needs to be richly fed and which can bear heavy dressings of the right kinds of manures. Practical men assert that the quality of tobacco grown on land which has been dressed with farmyard-manure in the autumn is usually better than that of tobacco which has been manured in the spring; and it is directed that when manure has to be applied in the spring it should be worked into the land as long before the plants are set out as may be possible. According to Nessler, tobacco grown upon fields which have borne tobacco the year before is often of exceptionally good quality. A. Mayer observed in Holland that the percentage of nitrogen in tobacco was larger on fields which had been manured in the autumn than upon fields manured in the spring, and he attributes this result to the more thorough nitrification of the manure which has been longest in the soil. But he noticed also upon fields which received nitrate of potash as a reinforcement that the best results were obtained where the farmyard-manure had been applied in the autumn.

Boussingault was disposed to attach considerable importance to the influence of climate upon the decomposition of manure in the soil. He sums up as follows. In warm, damp countries it may be conceived that it is a matter of indifference whether farmyard-manure is put into the ground quite fresh, or more or less thoroughly decomposed; for, thanks to the heat of the climate, the decomposition will be rapid enough anyway. But it may be otherwise in cold climates where the temperature which excites and maintains vegetation is of comparatively short duration, and must at once be taken advantage of. In such places the ground is so cold that during a great part of the year organic matters buried in it would be preserved with comparatively little change. Under such climatic conditions, there is no doubt that well-decomposed manures are preferable to those that are fresh and long. The extensive use of liquid manures in Switzerland, he suggests, is an illustration of the estimation in which quick-acting fertilizers are held in places where immediate advantage must be taken of a short summer.

Some Crops can Bear Manure.

Many instances might be cited from the experience of American farmers in illustration of the foregoing statement of Boussingault. In the Northern United States there need be little hesitancy in manuring Indian corn freely, for, unlike wheat and oats, and barring accidents, corn can stand up and yield grain even on very fertile land and when richly fed. Squashes, pumpkins and melons may be grown, near Boston, on spots where manure heaps have lain, or even on the compost heap itself. But in Cuba it would hardly be wise to apply much manure to maize, for there — as in the southernmost American States — it exhibits a strong tendency to run to leaves and stalks. Perhaps maize is seen in its fullest perfection in a moderately warm climate like that of Ohio and Illinois. So too, with oats, in Cuba the crop is practically a grainless grass, and oats are seldom sown there except to be mown as grass. In respect to winter wheat, it has been said that nowhere in the United States can it be safely grown on such rich land as is habitually devoted to wheat in England and Scotland. In Cuba, tobacco is cultivated only on sandy loams that are not too rich, and only in the winter season, when rains are infrequent and the conditions are not favorable for rank and rapid growth. The plant can grow indeed most luxuriantly during the hot, moist summer, but the leaves produced in summer are not esteemed. (Russell.) So too in Sumatra, tobacco is grown on rather poor soils which are but lightly manured, while in Europe this crop can be grown with profit only on rich soils that are heavily manured. (A. Mayer.)

Merit of Fresh Manure.

Having in view the climate of Central Europe, Walz, a noted German agriculturist, wrote with a great deal of force in favor of carrying fresh dung to the fields. He remarks upon the fact that, upon many South German farms, after the manure has all been hauled out in autumn, the dung-heaps are left to accumulate during half a year, not being disturbed again until the next spring; whereas during the summer season the manure is often hauled out upon the fallow fields after having lain in the yard no longer than 5 or 6 weeks. But it is noticed that under these circumstances there is always much more manure to haul from a given number of cattle in summer than in winter, — in places, that is to say, where the cattle are all the while kept in stall.

Attempts have been made to explain this fact on the assumption that an increase of dung is caused by the green food which is given to the cattle in summer. But this idea is refuted at once by the facts that the dung-heaps increase just as fast during April and May, before the animals get any green food, as they do afterwards, and that the rapid accumulation of dung in summer is just as well marked in the case of fattening cattle and draught oxen, that have received no green food. Manifestly the chief cause of this apparent increased production of dung is, that a smaller proportion of the dung is wasted by decay in the heaps when the heaps are new and small.

But, as Walz urges, it is good practice to carry the fresh dung to the field for the mere sake of availing one's self of the increase of bulk; for the fresh manure expends to better advantage, i. e., it may be made to fertilize a larger surface than if it were left to shrink in the barnyard heaps.

He narrates how his own attention was emphatically called to this subject, when he was a young man, by the circumstance that he had a field so situated that the manure had to be hauled upon it in winter. He computed how many loads of manure would dress the field, and proceeded to have the manure hauled out in February when the ground was frozen. He carried out 36 wagon loads in all, and had them piled up in two heaps. But when he came to spread the manure, seven weeks afterwards, there were only 24 wagon loads of it to be found.

His farm was at that time a good deal run down, and on the system which he had previously been following of never spreading anything but half-rotted dung, — in the belief that manure was best when used in that condition, — he had each year been unable to make manure enough to dress all his fields.

Hence it happened that he fell into the habit of hauling out fresh dung to make up the deficiency, so that he frequently had opportunity to compare the effect of the two kinds of manure where they were put into competition with one another upon the same field.

Indeed, it even happened that the fresh dung, being stretched as it were to the utmost to make up the deficiency, was spread rather thinner than the rotted dung. But Walz was never able to detect any difference either in the appearance of the crops, or the number of sheaves of grain, or in the yield of dressed grain.

So that by taking the two hints, especially the one offered by the shrinkage of the heaps of dung in the field, he was led to carry out methodically all the manure of the farm in the freshest possible condition; and the longer he practised this system, the more firmly was he convinced of its great superiority. From the time when he seriously began to use all the manure in the fresh state, he had no trouble in getting enough of it to dress all his fields.

Walz has suggested, that the loss of manure by decay may be seen very clearly by contrasting the effect of folding sheep with the effect obtained by using sheep-manure that has been hauled from the stable. In his practice, 200 sheep were folded for 240 nights, on the average of years, upon 18 Morgen of land. During the remaining 125 days of the year the sheep were kept, upon equally good food, 80 whole days and nights in stall, on the average of years, plus 45 nights. When in stall, the sheep were littered with from one-third to one-half a pound of straw per head and per day.

In May the sheep-manure was hauled out and spread for a rape-crop upon three Morgen of strong land contiguous to the land that had been folded upon. But during the six years that comparisons were made, the rape-crop was always as good on the land where sheep had been simply folded as upon the land that had been dressed with the sheep-dung, and in two instances the folded land carried better crops than the other; and precisely the same effect was noticed in regard to the winter grain that succeeded the rape, and in respect to all the crops that followed the grain in the rotation.

Hence it appeared that the stall manure of ⅓ the year went only one-sixth as far as the folding of ⅔ of a year, although 80 days as well as nights are to be counted in favor of the production of the stall manure, and although 124 cwt. of straw were commingled with the dung, and although the dung and straw were trampled down hard by the animals, so that the access of air was much less than it would be in a mere heap. The loss through decay was equal to the whole of the straw and half the droppings of the animals.

Mechanical Effect of Manure.

It is a common remark of farmers, that the character of the land upon which one or another kind of manure is to be put must be considered. Fresh, strawy manure, they say, might decompose readily enough on loams of light or medium character that are not too dry, while long manure too deeply buried in clay or very heavy loam might sometimes decompose there more slowly than would be desirable, because the compactness of the soil particles would hinder the access of air.

It is manifestly impossible, however, to make any general statements of this character which shall be true of all cases and places. Variations as to climate and rainfall, as to the times and seasons when crops are to be grown, and as to the kind of crops, will naturally bring in greater differences than those which subsist between fresh and rotten manure. Thus it has often been objected to horse-manure on light, sandy soils, that it decomposes there too rapidly, and shows less endurance or lasting effect than is deemed to be desirable. Hence, perhaps, one reason why many practical men think it best, on the whole, not to use horse-manure by itself, but rather in admixture with cow-manure and the dung of swine. But on the other hand, it has been urged that horse-manure helps to loosen heavy land by means of the straw with which it is ordinarily admixed. Most commonly, perhaps, it has been held that horse-manure and manure from sheep-stables should be applied by preference to cold, clayey loams, or to moist soils rich in humus, where decay will not be too rapid, and where these "hot" manures will tend to warm and enliven the land. The, comparatively speaking, cold and slowly fermentable cow-manure, on the contrary, is preferred for warm, light soils, rather than for those that are stiff, or cold, or rich in humus.

Influence of Manure on Soil-moisture.

Beside these palpable mechanical effects, there are others, still more important, due to the soluble matters in the manure acting to alter the arrangement of the soil-particles and thus to change the relations of the soil towards the movements of water within it and to increase or diminish its power of holding water. It is known to practical men that farmyard-manure, and other fertilizers, have very important effects in that they enable crops to withstand droughts, and it was observed many years ago by F. Schulze, on the occasion of his investigation of the capillary movements of saline solutions, that the soluble constituents of manure must exert no inconsiderable influence on the texture of soils. This matter has been studied in some detail by M. Whitney, who has proved that solutions of several substances lower the surface tension of water very considerably, and lessen the capillary power of the soil to lift water from below to supply that lost by evaporation and transpiration. He finds that an aqueous extract of stable-manure has less lifting power than pure water, and, as will be explained under Lime, he has noticed some very curious and important reactions when lime and stable-manure are mixed with soils and sands.

Another point of interest is the rapidity with which the soluble portions of stable-manure may clog a soil and hinder the flow of water through it. Whitney found, on passing a filtered extract of stable-manure through a soil which had 50 % by volume of empty space, that the rate of flow speedily decreased to such an extent that the experiment could not be continued. After 6 successive 100 cc. portions of the liquid had been poured upon the soil, some 2000 minutes were required for the passage of 100 cc. These results are so very emphatic that Whitney has been led to ask whether the application of fertilizers should not properly be regarded primarily as a means of regulating the water supply of crops rather than as a mere providing of plant-food. He has in fact suggested, as a probable hypothesis, that the most important effect of stable-manure, and of fertilizers generally, may be due to their influence in changing the relations of soils to moisture rather than to the amount of plant-food they may add to the soil.

Shrinkage of Manure-Heaps.

The shrinkage above spoken of must often be very large. Gazzeri found long ago that horse-manure lost in the course of four months more than half the dry matter that was contained in it before the putrefaction. Several of the older agricultural writers have insisted that 100 loads of fresh manure may be reduced to 70 or 75 loads after two or three months' fermentation, and even to less than 50 loads at the end of a year. Payen found in horse manure taken from a hot-bed after the fermentation had run its course and the manure had become cold, no more than 1.58 % of nitrogen, reckoned on the manure dried at 212°, in place of 2.07 % in dried fresh manure. Voelcker, in his elaborate experiments on farm-manure, noticed that mixtures of dung and litter lost from 30 to 60 % of the original weight in the course of 6 to 12 months' fermentation; or, throwing water out of the account, the loss of dry matter amounted to from one-half to two-thirds of that contained in the fresh manure. The proportion of organic matter diminished steadily from month to month.

One sample of the mixed manure, which when dried at 212° F. contained originally 83.5 % of organic matter, contained no more than 53 % of it after the heap had been left lying out of doors for a year. But while the quantity of the manure diminished so seriously, the quality of it suffered no great depreciation when the fermentation was well regulated. On the contrary, the loss of actual plant-food was inconsiderable, when the fermentation was not too long continued.

Even in a heap of manure exposed to the weather throughout the year, it appeared that the quality of the manure improved during the first three or four months of fermentation, in that the proportion of soluble matters increased to such an extent that the efficacy of the manure must have been considerably enhanced. Subsequently, this manure suffered deterioration when rains washed out from it soluble matters and a considerable portion of the available nitrogen. This waste by leaching was especially rapid in the case of some manure that had been spread out upon the surface of the ground, but it was conspicuous also in heaps of manure, and was the more clearly evident in proportion as the manure had been longer kept. It appeared, indeed, that although rotten manure lost weight more slowly than fresh manure which was exposed to similar conditions, yet the rotten manure was more liable to be injured by rain because it contained a larger proportion of soluble matters than the fresh manure.

While recognizing the fact that for certain purposes fresh farm-manure can never take the place of well rotted manure, Voelcker urges that there is no advantage in keeping manure too long. Six months, perhaps, may be taken as a limit. He says, "The most effectual means of preventing loss in fertilizing matters is to cart the manure directly to the field whenever circumstances allow this to be done."

Wolff records a loss of 54 % in the case of an 80-ton heap of cow-manure that was left for a year freely exposed to sun, wind, and weather. The loss was in no sense due to evaporation of water, for, on stating the matter in terms of dry substance, i. e., fresh and rotten manure from which all water had been dried out at 212° F., it appears that the dry manure had lost 66¼ % of its weight. This fact of an absolute loss of substance must be kept in view whenever analyses of fresh and of rotted dung are compared, for the figures of the analyses are merely relative, and they often give no very distinct indication as to how much of any particular ingredients has been lost.

It may here be said that, as a general rule, by far the largest part of the matter lost from manure-heaps through decay consists of compounds of carbon and hydrogen, which are not to be classed among fertilizers, and which, from the farmer's point of view, are really non-essential. On examining a weather-beaten clot of cow- or horse-dung as it lies in a pasture, or on stirring a small quantity of the fresh dung in clear water, it will be noticed that the dung of these animals consists in good part of short pieces of undigested hay or grass; and it may be said even of the clear dung — though much more forcibly of ordinary manure admixed with litter — that it is to the oxidation of useless organic matter that the shrinkage of manure-heaps is to be attributed for the most part.

Voelcker's Analyses of Farm-Manure.

Some of the figures of Voelcker's analyses of farmyard-manure have been set forth already in the general table on page 241. The more extended statement here given is still to be regarded as a very brief abstract of Voelcker's original memoir. The material operated upon was a mixture of cow, horse and hog-manure; and it is to be noticed that two separate parcels of manure were studied, — the samples described at 6 and 8 months old being different from the others.

	Fresh Manure, 14 days old. Nov.	From Heap 3½ mo. old. Feb.	Under Cover 3½ mo. Nov. to Feb.	Spread 6 mo. from Nov. to May.	Well Rotted.	
					6 mo. old.	8 mo. old.
Water	66.17	69.83	67.32	80.02	75.42	73.90
Soluble organic matters . . .	2.48	3.86	2.63	1.16	3.71	2.70
Soluble inorganic matters . . .	1.54	2.97	2.12	1.01	1.47	2.06
Insoluble organic matters . . .	25.76	18.44	20.46	11.46	12.82	14.39
Insoluble inorganic matters .	4.05	4.90	7.47	6.35	6.58	6.95
Nitrogen	0.64	0.74	0.75	0.54	0.61	0.76
Soluble in water	0.15	0.27	0.17	0.08	0.30	0.15
Insoluble in water	0.49	0.47	0.58	0.45	0.31	0.61
Phosphoric acid	0.32	0.32	0.45	0.27	0.45	0.12
Soluble in water	0.14	0.14	0.15	0.09	0.18	0.06
Insoluble in water	0.18	0.18	0.30	0.18	0.27	0.06
Potash	0.67	1.22	0.88	0.42	0.49	1.08
Lime	1.19	1.34	1.92	1.97	1.78	2.27
Magnesia . . .	0.15	0.05	0.08	0.09	0.14	0.04
Ammonia, free .	0.03	0.02	0.02	0.01	0.05	0.02
Ammonia, as a salt	0.09	0.06	0.05	0.05	0.08	0.05
Nitrates	None.	Traces.	Indistinct traces.	None.	None.	Decided traces.

Several highly interesting facts are made manifest by these analyses; particularly on contrasting the figures which refer to fresh manure with those relating to manure six months rotted. The fresh manure was an intimate mixture of the droppings of horses, cows and pigs, — together with the straw used as litter — that had lain in the dung-pit not more than 14 days, at a time when no rain had fallen. The rotted manure was a well-mixed sample of dark brown, almost black color. It was not taken from the same heap as the fresh manure, but from the bottom of a manure-pit, though it was produced under the same circumstances and by the same kinds of animals as the other. It was at least six months old and appeared to be well-fermented, short manure.

The analyses show that the proportion of soluble matters in fresh, long manure is comparatively small. On the other hand, the proportion of insoluble matters, especially of organic matters from the straw, is very large. Both these circumstances naturally tend to explain a certain slowness of action which has often been attributed to long manure. Through the presence of the straw, the proportion of soluble nitrogen in the fresh manure was reduced to a very low figure. Much the larger part of the nitrogen in the fresh manure was in an insoluble condition. But it is none the less true that the soluble nitrogen was a specially valuable form of plant-food. That it was a constituent of substances rich in nitrogen appears from the facts that while each 100 lb. of the soluble organic matters of the fresh manure contained 6.04 lb. of nitrogen, there was no more than 1.92 lb. of nitrogen in the 100 lb. of insoluble organic matters.

On comparing the analyses, it will be seen that the proportion of insoluble organic matters in the manure diminished very much during the process of fermentation, but that the nitrogen did not waste away anything like so rapidly as the other constituents of the organic matter. Indeed, load for load, the manure became much richer in respect to nitrogen as it changed from the fresh to the rotted condition. Thus, while in the dry, fresh manure, there were 76.15 % of insoluble organic matters, containing 1.46 % of nitrogen, there was almost as much nitrogen (1.26 %) in the 52.15 % of insoluble organic matters that were contained in the dry, rotted manure. In other words, each 100 lb. of the insoluble organic matters of the fresh and the rotted manures contained respectively 1.92 lb. and 2.41 lb. of nitrogen. In each ton of the dry material there was 38 lb. and 48 lb. of nitrogen accordingly as the manure was fresh or rotted. Or, supposing the two kinds of manure were equally moist, there was much more nitrogen in the old than in the recent product.

During the earlier months of the fermentation a considerable amount of the organic matter in the manure became soluble in water, so that at the end of six months the proportion of soluble organic matters was twice as large in the well-kept manure as it had been in the fresh manure. But the chief part of this change occurred during the first three months, and it was evident enough that no advantage can be gained on this account by keeping manure too long. Meanwhile, the soluble nitrogen increased from 0.44 % to 1.21 %, that is to say, the proportion of soluble nitrogen became so much larger during the process of decay that each 100 lb. of the dry soluble organic matter from the rotted manure contained 8.02 lb. of nitrogen, while there was no more than 6.14 lb. of nitrogen in similar material obtained from the fresh manure.

Naturally enough, the proportion of ash-ingredients increases during the fermentation of well-kept manure because a considerable amount of the organic constituents of the manure escape in the form of gas. It will be noticed, on comparing the fresh and the rotted manures, that the percentage of insoluble inorganic matters was more than doubled. There was in fact, an increase from 12 % of insoluble ash in the dry, fresh manure to 26.8 % in the dry six-months rotted manure. That this increase really depended on the waste of organic matters appears from the facts that while the fresh manure dried at 212° F. contained 83.48 % of organic and 16.52 % of inorganic matters, the rotted manure, similarly dried, contained only 68.24 % of organic matters against 31.76 % of inorganic.

It is to be observed furthermore that the proportion of soluble ash-ingredients in the six-months rotted manure is larger than it is in the fresh manure. The principal constituent of the soluble part of the ashes of fresh manure is silicate of potash, and it is noteworthy that even in fresh manure a considerable amount of phosphate of lime is in the soluble condition, but in the rotted manure there was found a still larger proportion of soluble phosphate of lime — a result which consists with the well-known fact that in the decay of bones the solubility of the bone-earth is promoted by the putrefaction of the ossein.

On the whole, the well-kept, well-rotted manure was richer, weight for weight, than the fresh manure in respect to soluble fertilizing constituents and to available nitrogen. It would probably have produced a more immediate and a more powerful effect on vegetation than the long manure. In Voelcker's own words, "The practical result of these changes is that fresh manure in ripening becomes more concentrated, more easily available to plants, and, consequently, more energetic and beneficial in its action."

The other analyses mentioned in the table were of samples of manure that had been exposed under varying conditions, to test the influence of the weather. It will be noticed that the injurious effect of rain is plainly evident in the case of the manure that was spread and left for a long time exposed. As the analyses show, the mixed farm-manure, whether fresh or rotted, contained no more than mere traces of ammonia in the volatile form, and only trifling amounts of ammoniacal salts. It would appear that during the decay of such manure but little nitrogen escapes as volatile ammonia, though considerable quantities of ammonia and of other valuable matters may be leached out from dung-heaps by rain.

In Voelcker's opinion, as stated some years after the date of these analyses, " Neither fresh nor rotten dung contains an appreciable amount of free ammonia. Under good management, dung loses none of its essential fertilizing constituents, and neither sun nor wind expels any volatile ammonia compounds from dung. It appears, therefore, quite unnecessary to keep dung in closed buildings. In localities where much rain falls, and a sufficient amount of litter cannot be used to absorb the liquid portion of the manure, it is advisable to have the dung-yard roofed in and the sides open; but where sufficient litter can be spared in the making of the manure to retain, even in rainy weather, the liquid portion, it is even unnecessary to put a roof over the dung-pit. No loss in fertilizing matter is experienced when dung is carted and spread upon the field as soon as it is possible to do so after it is produced."

As bearing upon this question, it is to be noticed that Dehérain has urged that his own experiments show that a large part of the insoluble nitrogenous matters in fresh manure become soluble in the course of time, through the action of the alkaline carbonates which manure contains. The matters thus dissolved soak into the straw and impregnate all parts of the heap, and some of them pass away in the dung-liquor, which is black because of their presence. It often happens, when solutions of this black matter slowly trickle out from the sides of an old manure-heap, that, as the water evaporates, the material is left in the form of stalactites. It is to be noted, however, that this statement applies more particularly to very moist and thoroughly rotted manure-heaps, such as may often be seen on the continent of Europe. Wolff urged long ago, when treating of the increase of the percentage proportion of soluble nitrogen compounds and of soluble organic matters in manure as it decays, that this increase can only occur to an appreciable extent in exceptional cases, as in firmly trodden manure kept in very moist pits, where air is excluded. Under such conditions as these, processes of chemical reduction will occur; sulphides will be formed, and apparently ammonium compounds also.

It is of interest to recall the fact, that the simultaneous formation of sulphides and ammonium compounds has sometimes been noticed in the humus of peat-bogs. In Wolff's own experiments, where cow-manure was allowed to decay in small heaps, there was a considerable diminution of soluble nitrogenous and organic matters, and of ammonia also, according as the process of decay progressed.

Shall the Land be Manured, or the Crop?

The question whether dung shall be applied in the fresh condition, or rotted, appears to be intimately connected with another which has not a little exercised the minds of farmers; viz., whether it is best to manure heavily and seldom, or lighter and more frequently. Much will depend, of course, upon the character of the soil, and practical men have long held that, while it is safe enough to manure clays heavily and seldom, it is better, on the whole, to dress sandy loams lightly and often. (Thaer.) As regards calcareous soils, it is a matter of popular belief in Europe that manure acts quickly upon them, and has but little endurance. It is held that such soils should be manured abundantly and often, and that there is little risk that too much manure will ever be applied to them.

Gasparin was accustomed to lay no little stress on the need of putting enough manure on the land in the first place to "saturate" it fully. He argued that, since certain constituents of the soil, notably clay, iron oxide, humus (and hydrous silicates), have the power of absorbing and holding very considerable quantities of plant-food, it is essential that the land should, once for all, be surcharged with manure, in order that these fixing substances may be fully saturated with plant-food, so that they shall henceforth serve as reservoirs to supply nutriment to the crops, instead of acting as absorbents to withdraw food from the roots, i. e., from the soil in which the plant is standing.

On good soils, which have been brought to the "point of saturation," manure may be applied most profitably for the production of merchantable crops, for the new additions of manure will now produce the full effect of which they are capable. Whereas on land not fully saturated, the new additions of manure may not produce more than 80 %, 75 %, 50 %, or even a smaller percentage of the effect which might properly be got from them. Unsaturated land had better be devoted to forage crops than to grain or other merchantable products. The high cost of producing the initial saturation compels most farmers to work up towards it gradually, and prevents them from trying to put their land into first-class condition all at once.

While admitting the force of this reasoning, the general conclusion of practical men seems to have been, that, excepting cold, clayey land, where large quantities of manure may occasionally be applied for the sake of improving the physical condition of the soil, it is usually best, on the whole, to manure rather lightly and frequently. The quantity of manure to be put upon farm land at any one time has almost always been made to depend, in some measure, upon the character of the soil; for it was recognized very early that manure may safely enough be applied freely to compact clays, such as are not readily permeated by the air, and be counted upon as a store competent to produce useful effects during several years. Whereas, on light, sandy soils, and especially on sandy soils which are calcareous, manure sometimes decomposes so rapidly that it is not easy to recover, in crops, the full goodness of even moderate applications of it. These experiences naturally led to the putting of small quantities of manure at frequent intervals on "leachy" soils, and to the application of much heavier dressings of manure to stronger lands. In addition to these teachings of old experience, it appears to be true that a tendency to apply manure often, and in somewhat smaller quantities than were formerly usual, has become stronger since the time when artificial fertilizers came into general use. Nowadays it is customary to use powerful soluble fertilizers of quick action, and to apply no very large quantity of them at any one time. As has been said, the idea now is to manure the present crop, while formerly everyone thought and spoke of manuring the land. The modern idea is justified by what has been learned in recent years in explanation of the peculiar merit of fresh manure; concerning the destruction of the nitrogen in manure, both by fermentation and by change to inert humus, with the lapse of time; and as to the conversion of the dung-nitrogen to nitrates, which may leach out of the land unless the roots of a growing crop stand ready to absorb and consume them.

Dung-nitrogen Wastes Slowly.

It is well understood, of course, that, in the field, the waste of nitrogen from farmyard-manure is much less, and is much less rapid, than the waste of nitrogen from the artificial fertilizers, nitrates and ammonium salts. Much of the nitrogenous organic matter in farmyard-manure decomposes in the ground so slowly that it can neither be used freely by crops nor wasted rapidly by drainage. In the experiments of Lawes and Gilbert, where farmyard-manure was applied for wheat every year for 25 years in succession, analysis showed that the top 9 inches of soil contained nearly twice as large a percentage of nitrogen as the corresponding layers of contiguous plots of land that had been dressed with artificial fertilizers, and which, though they had received much less nitrogen annually, in the form of ammonia salts or nitrates, had nevertheless yielded larger crops.

In their experiments on permanent grass-land, one plot received 14 long tons of farmyard-manure, containing about 200 lb. of nitrogen per year and per acre, for 8 years, and gave an average produce of 4,800 lb. of hay, against 2,700 lb. on the unmanured plot. During the next 11 years, neither farmyard-manure nor any other fertilizer was applied to the plot which had previously been dunged, and the average produce for the 11 years was 3,800 lb. of hay against 2,200 lb. on the "unmanured plot" which had received no manure from the beginning. The total increase during the 8 years when manure was applied was 17,000 lb. of hay, and the total increase during the next 11 years, due to the influence of the dung previously applied, was 17,200 lb.; but it was noticed that the crops fell off very much during the later years, and that they averaged considerably less than one-half as much over the last 5 as over the first 6 of the 11 years. In the words of Lawes, "It is probable that, during the whole 19 years, not more than two-thirds as much nitrogen has been removed, in the total produce of hay, as was supplied in the manure, and the increase of nitrogen over that contained in the permanently unmanured produce has probably not been one-fourth as much as was supplied."

In other experiments, where 14 tons of farmyard-manure had been applied per acre to one plot in a barley-field during 20 successive years, the application of dung was stopped on one-half the plot and continued on the other half. During the next three years, the average produce of the now undunged acre was 44 bushels of dressed grain and 2,684 lb. of straw; but on the acre where the application of manure was continued, the average yield during the same three years was 52.5 bushels of dressed grain and 3,502 lb. of straw. That is to say, there was, on the average, 8.5 bushels more of grain and 818 lb. more of straw, per year and per acre, where the manure was applied afresh, than where the application of manure had been discontinued. Although the yield continued to be large, after the application of the manure had ceased, thanks to the residues from the previous manuring, it nevertheless appeared that the crops did not reach the maximum which the characters of the seasons admitted of when the land was dressed anew. Notwithstanding the large amounts of nitrogen, and of other kinds of plant-food, which must have accumulated in the land, the fresh application of manure did good service. In their experiments with potatoes, also, alluded to under the head of Endurance of Manure, strong evidence was adduced of the advantage of applying manure frequently.

It is to be remembered, nevertheless, that the old plan of giving the land once in a while a heavy dressing of manure which should suffice for a term of years, was connected with, or rather it was based upon, various schemes of rotations of crops, and that clover, or some other nitrogen-bringing plant, was grown at such intervals in the rotation as should enable it best to help out and support the manure.

At the South of France, on soils fairly well supplied with moisture, Gasparin observed that the effect of stable-manure endured until the third year, though he estimated that a crop of wheat grown in the first year after manuring would remove 639 lb. of nitrogen for every 1,000 lb. of nitrogen in the manure, and that the wheat-crop of the second year would remove 361 lb. of nitrogen. In case the land was irrigated so that two crops could be grown in the first year, the decomposition of the manure would be accelerated, and practically its nitrogen would be used up in that year.

Guano applied by Instalments.

Some of the experiments that have been made with Peruvian guano applied by successive instalments, illustrate very well the significance of fresh manure, for the constituents of guano are closely analogous to those in fresh animal excrements, and they speedily undergo change in the soil. It is often complained of guano, that its effects are fugitive, but the real trouble is evidently with the clumsy methods of applying it which are in ordinary use. So it is with dung and urine, and if it were but possible to bring these fertilizers to the fields continually in appropriate quantities in the fresh condition, the best possible utilization of them (chemically speaking) would doubtless be obtained.

Stoeckhardt applied guano at the rate of 1.5 Centner to the Morgen) = 0.631 acre), and obtained the following relative weights of sheaves of oats: —

	In the Year 1857.	In the Year 1858.
Guano all applied at seed-time	100	100
Half at seed-time and half before the crop had begun to shoot	147	113
One-third at seed-time, one-third before shooting, and one-third before blossoming . .	168	133

In 1861, his experiments resulted as follows: —

	On a Poor Sandy Soil.	On a Strong Clay Soil
Guano all applied at seed-time	100	100 (assumed.)
Guano applied twice at seed-time . . .	131	134
Guano applied after the seed once . . .	100	100 (assumed.)
Guano applied after the seed twice . .	115	112
Guano applied after the seed thrice . .	162	161

In considering such experiments as these, it must never be forgotten that beside supplying the crop with food, fertilizers often act as ameliorants either directly by improving the capacity of the land to hold water, or, indirectly, by enabling the roots of plants to penetrate more deeply in search of moisture than they could have done if food had been less abundant. Hence one reason for arguing in favor of manuring the land, as well as each particular crop. This point may be illustrated by a reference to some experiments by Lawes and Gilbert, as set forth in the following table, which shows the average yield (total produce) of certain crops, both under ordinary conditions, and in a year (1870), of extreme drought.

	Hay. lb.	Wheat. lb.	Barley. lb.
Average yield per year and acre, without manure	2,391	2,398	2,453
Yield in drought of 1870	644	2,002	1,489
Deficiency in 1870	1,747	396	964
With farmyard-manure, average	4,604	6,016	5,856
With farmyard-manure in 1870	1,556	5,092	4,949
Deficiency in 1870	3,048	924	907
With ammonia salts and mineral fertilizers, average	5,794	6,267	5,786
With ammonia salts and mineral fertilizers, in 1870	3,306	5,836	4,287
Deficiency in 1870	2,488	431	1,499

These results indicate clearly how helpful fertilizers, and especially dung, may be to grain-crops in times of drought, and they illustrate also the well-known fact that grass is apt to suffer more than grain in long-continued dry weather. The barley grown on the dunged land doubtless profited especially from the increased power of the soil to hold water in its upper layers, due to the presence of the manure.

Lawes and Gilbert have stated that, unless a very great excess of rain has fallen, water never runs from the tile-drains in those plots of their experimental field which have been dressed year after year with dung, because the manure has greatly increased the porosity of the soil. "The fact is that whilst the pipe-drains from every one of the other plots in the experimental wheat-field run freely, perhaps 4 or 5 or more times annually, the drain from the dunged plot seldom runs at all more than once a year, and in some seasons not at all." It was found, on trial, that the dunged land when saturated with water retained, within 12 inches from the surface, an excess of water equivalent to about 1.5 inch of rain more than was held to the same depth on adjacent plots that were unmanured, or manured with artificial fertilizers. Not only did very little water escape through the drains of the dunged land, but the proportion of nitrates in this water was less than that in the water which escaped from plots fertilized with ammonium salts.

Litter needs to be Rotted.

Practically, as a mere matter of labor, stowage capacity, and convenience, it would be difficult for most farmers to bring more than a small portion of their barnyard-manure to the land in the fresh condition.

Moreover, fresh stable-manure almost always contains in practice an admixture of straw, cornstalks, and other "long" litter, which would seriously interfere with the application of the manure to the land, and which render it unhomogeneous also. It is true that, on some kinds of land, the long manure might do good, physically speaking; i. e. many a heavy soil might be lightened by means of it. In the cultivation of newly-reclaimed polders (silt-land) in Belgium, it is thought to be essential to success that, when grain-crops are harvested, the straw shall be left standing knee-high, so that by plowing in this tall stubble, the too compact soil may be duly lightened and aerated. But, to say nothing of the trouble of incorporating it with the soil, it might often happen on soils in good tilth, in case unrotted manure were buried directly, that a good part of the straw would escape decomposition, and consequently exert no immediate fertilizing action. It might even do serious harm by lightening the land unduly.

On light lands, in some parts of England, it was a rule of practice that manure from the straw-yard should all be applied to the land in the autumn, and intimately mixed with the soil; for if laid on in the spring, it would keep the land open and so much increase the effect of drought that the crop might be greatly injured or even destroyed. In any event, it might happen that the dung alone would go to nourish the present crop, and an entire season might elapse before the straw had decomposed sufficiently to render its constituents fit food for plants.

It has sometimes been urged that these last considerations do really indicate the limit to which the fermentation of long manure may be profitably pushed; to the point, namely, where the straw or other litter begins to lose its integrity, and admits of being torn apart with scarcely any effort.

It is probable that this point of incipient change is really the one to be aimed at as the point of greatest advantage, all things considered, though it is manifest that only a comparatively small proportion of a year's stock of manure can be employed in just this or in any other one particular condition. The convenience of each farmer will, of course, determine how much of his manure he will carry out green, and how much after fermentation. But it is none the less desirable that the best way of doing the thing should be kept in view and striven for. It is to be remembered withal, that when straw has been drenched with urine or with dung-liquor, the alkaline constituents of these liquids serve to dissolve the albuminous matters and certain other constituents of the straw, and thus help to disintegrate it.

Merits of Rotted Manure.

It is to be remembered that certain anaerobic ferments act chiefly to destroy the woody fibre in manure, both that in the litter and that in the dung itself, so that the proportion of fertilizing matters — nitrogen, phosphoric acid and potash — may be actually larger in the well-rotted product than in the fresh manure, although the character of the nitrogen compounds must have been very thoroughly changed. For some purposes, the nitrogen in well-rotted manure is highly esteemed, while for other purposes the nitrogen (urea) of fresh manure is to be preferred. On the whole, there can be little doubt that the chief reason why short manure is commonly thought to be better than long manure must depend upon the fact that, provided the rotting has been thorough, the short manure is really a highly concentrated product. Much of the shrinkage in volume which occurs when manure ferments tends simply to concentrate the fertilizing matters in it through the loss of non-essential substances, such as cellulose or woody fibre, for example, though, as has been urged already, some part of the diminution is due to an actual waste of useful ingredients.

Boussingault, for his part, did not hesitate to insist that there may be "an immense advantage" attending the fermentation of manure, in that the product, provided that the fermentation has been discreetly controlled, may be of greater value under a smaller bulk and less weight. He urges the very important saving of carriage in the case of the fermented dung, as, for example, when it has lost a third of its weight by the process.

The remark is true, not only in respect to the hauling out of manure, but also as to the distributing of it. It is possible, of course, to lay long, strawy manure in the furrows as fast as they are made, so that the plough may cover it in at the next turn, as is often done in fact, in certain European localities, on heavy clay land; but the labor thus expended must usually exceed in value whatever chemical substance would have been lost in case the manure had been fermented, and the waste of labor is palliated rather than done away with when such manure is worked into the land by means of machines, such as disk-harrows or the like.

One advantage to be credited to long manure on clays, in situations where the soil would not be liable to become too dry, is that it lightens the soil so that air is admitted freely enough to nitrify the strawy manure more rapidly than well-rotted manure could be nitrified in its place. But there is always a risk that soils charged with strawy, unrotted manure may be left too loose and open for the growth of seeds or young plants, especially if dry weather should set in soon after the sowing.

The most thoroughly rotted manure at one's disposal would naturally be put upon light soils, and upon those highly cultivated fields which are to be managed as if they were gardens; the long manure would be relegated to heavy land and to crops not requiring specially careful management; while for a large portion of the farm the half-rotted material just now described might be preferable, all things considered, to either of the others. It is known that, while the nitrogenous constituents of urine and of fresh manure are apt to nitrify very rapidly in light soils that are not too dry, the constituents of old, well-rotted manure nitrify in such soils slowly and steadily and maintain a constant supply of easily assimilable food. It is to be remembered, withal, that, from the discussion in Chapter XII of experiments on the comparative value of nitrates and ammonium salts as plant-food, it has appeared that some kinds of crops may perhaps prefer the nitrogen in old manure to that in fresh manure, while some other plants may do best when fed with urea and the other nitrogenous constituents of freshly voided excrements.

One reason why thoroughly rotted stable-manure is so much esteemed is, that, taking the whole mass of it into consideration, it may act more quickly than long manure. A larger proportion of each ton of the mixed matters is already in a condition fit to be taken up by the roots of plants. This consideration is doubtless more important in the case of spring wheat and of barley than in that of some other kinds of plants, and it was more important formerly, in the days when artificial fertilizers were not to be had, than it is now. The life of spring-sown grain-plants is comparatively short; their growth is completed in the course of a few months, and the period during which they can consume manure may be counted by weeks. Hence it may happen that, while some part of the fresh manure would act only too speedily, the decomposition of the remainder might not be rapid enough fully to supply the wants of the crop. But in the case of plants of another habit of growth, such as Indian corn, for example, this objection would have less weight.

In dry seasons, and particularly for light soils, the quick action of an abundant dressing of well-rotted manure would have the merit of giving the crop a start, so as to enable it the better to survive the subsequent hardships. The humus of the well-rotted manure would, moreover, often serve a better purpose, in case of drought, than the long, unfermented litter from which it was derived.

Straw must be Rotted.

The importance of rotting thoroughly the straw in farm-manure is often insisted upon by practical men in grain-growing districts. Thus, in laying down rules for the treatment of manure, some of the Western New York farmers have enjoined, 1st, that the barnyard should be so arranged that no part of the manure can run out from it; 2d, that straw enough should be used to absorb all the liquid portion of the manure; and, 3d, that the strawy mixture, when hauled to the fields in the spring, should be piled in rather large, high heaps, with square sides, and with the top somewhat hollow in order to hold water.

They say that, if the top were built rounding, or slanting like a roof, so little water would soak into the heap that the straw would not rot. Even when a heap of very strawy manure is well built, with a saucer-like depression on top, its sides will not decay. In order to rot the straw in them, the sides may be pared off after a while, and thrown on top. A heap of strawy manure that has been well built in the spring will be in condition to be cut with a spade by July. Practically, it would be used in August or September on winter grain. Manifestly, the addition of "preservatives"— such as gypsum, salt or Stassfurt salts — to manure of this kind would be likely to do more harm than good. It is to be observed, also, that such long, dry manure as this of which the New York farmers speak, would not profit by being kept under cover. Indeed, it would be apt to suffer injury if the heaps just spoken of were made in sheds. Unless the manure be at least three-quarters cow-dung, the keeping of it in sheds is said to be inadmissible. Theoretically, sheds might serve well enough for keeping the manure from cows in New England, and yet be of no use, or be worse than useless, for the manure of farms that are devoted to grain-growing, unless, indeed, the arrangements of the grain-farm are such that the straw shall be fed out to stock in conjunction with some kind of wet food, like distillery refuse, or the potato-slop and beet-root pulp of Europe. The tendency of manure to injure itself by fire-fanging is one danger to be avoided, as well as the risk of leaching by rain. Sheep-manure or horse-manure, left to itself under a shed, would be liable to fire-fang.

Even out of doors, heaps of horse-manure are apt to suffer, unless frequently rained upon. In building such heaps, it is well to throw in occasional layers of peat or loam, to hinder obnoxious fermentations. On the other hand, if manure were exposed too long to an excess of moisture, and particularly if it were admixed with leaves or peat rather than with straw, it might pass into a cold, sour condition, and form faulty humus analogous to that in a peat-bog. So, too, if acid substances were admixed with manure, the fermentation of it would be checked, and the straw or other litter would not be decomposed. On this account, it may well be doubted whether it would be wise to add sulphuric acid, or even copperas, to manure, though such additions have been proposed as a means of "saving the ammonia."

In experiments made by Frear in Pennsylvania, the manure produced in a stable of 30 cows and 10 horses (where the animals were littered with the minimum amount of straw and sawdust consistent with cleanliness) was stored in two similar large and compacted heaps, one of which was kept out of doors in a dished yard, the surface of which was covered with puddled clay, while the other heap was kept under a shed which was open on one side and was wholly above ground. It appeared, both in the summer and in winter, that the open-air heap contained more moisture than the other, and that during the whole year less material was lost from the open-air heap than from the one in the shed; though the heap in the yard suffered slightly from the leaching action of rain. In summer, there was a larger loss of organic matter from the out-door heap than from the sheltered heap, but in winter the reverse of this seemed to be true. The loss of nitrogen agreed with that of organic matter, and it was evident that this impacted manure suffered especially from overheating under the shed in the winter, and when exposed to the sun in the summer.

From a general view of the subject, it would appear that, although some system of ensilaging manure might be theoretically excellent, the plan is hardly called for as regards cow-manure, which can be managed fairly well in less costly ways; while for manures that contain much straw that needs to be rotted, ensilaging is plainly inadmissible. For preserving fresh human excrements, silos may serve a good purpose. The Chinese have, in fact, used them to this end in their rice-fields time out of mind.

Nitrates hardly form in Dung-heaps.

It is not easy to speak in any very definite or authoritative way about the formation of nitrates in the dung-heap. Undoubtedly some nitrates and nitrites are formed near the surface of old heaps of manure, in spite of the fact that rotting manure must act as a reducing agent, and so tend to hinder their formation. Voelcker found considerable quantities of nitrates, though not enough to estimate quantitatively, in the dark-brown liquid, leached out by rain, that drained away from an old, well-rotted heap of manure, consisting of a mixture of the dung of horses, sheep, and stall-fed cattle; the inference being that the nitrifying ferments were able to live and work at or near the surface of the heap. But in a still darker and much more concentrated dung-liquor, that had drained out of a heap of fresh horse, cow, and hog-dung, he could detect only traces of nitrates. He noticed, also, that the liquid from the fresh dung-heap contained less than half as much combined ammonia as the other, manifestly because a good part of the organic nitrogen compounds natural to the fresh manure had not yet suffered decomposition.

Experiments by Holdefleiss go to show that comparatively little nitre forms in heaps of manure which are kept constantly moist by repeated applications of dung-liquor, though appreciable quantities may be produced in earth-covered heaps, and in those on which phosphatic gypsum has been scattered. The presence of Stassfurt potash salts on the other hand decidedly hinders nitrification, manifestly by poisoning the ferments. In the following table, the amounts of nitric acid are stated in per cents of the total nitrogen originally contained in the manure. In each case, the samples examined were taken from heaps of well-conditioned manure that had been kept for several months.

Manure.	Heaps kept moist with dung-liquor. Nitric Acid. %	Ammonia. %	Heaps not moistened. Nitric Acid. %	Ammonia. %
Covered with earth	8.5	6.6	18.00	. . .
Strewn with phosphatic gypsum . .	4.6	6.5	10.13	0.54
Strewn with potash salt	0.6	6.6	7.17	3.75

Alexander Müller found that, while urine that had been diluted with a great deal of water nitrified rapidly without emitting any odor, a quantity of faeces that had been mixed with 400 parts of water continued to give off offensive odors of putrefaction for months, and was only very slowly subject to nitrification.

Forking over of Manure.

The common practice of turning over manure, so as to expose it to the air, that is to say, the tossing up of the manure from a compact heap into a loose heap, must tend to the formation in time of nitrates in some parts of the heap, and may have been in some part justified formerly by this consideration, though commonly the forking over is resorted to either to check fermentation when the heap is in danger of getting over-heated, or to excite new fermentation when the first quick action has abated, in order to hasten the decay of the litter. As has been stated on a preceding page, the activity of ferment organisms — even that of anaerobic ferments which have become sluggish — is accelerated by admitting to them fresh supplies of air.

In general it may be said that the purpose of the forking is to check or promote, i. e. to control, fermentations of other kinds than those which cause nitrification. It is not improbable, indeed, that the "tempering" of the manure, i. e. a mitigation of its rankness by changing the character of the nitrogen compounds originally contained in it, may have been of considerable importance at a time when the farmer's first thought was to grow heavy crops of grain by means of farmyard-manure. For, in order to obtain such crops, care has to be taken to avoid too rank a growth of straw, such as would almost inevitably follow heavy applications of fresh manure.

Loss of Ammonia?

A good deal used to be said about the loss of ammonia during the fermentation of manure, and numerous receipts for saving this ammonia by means of gypsum, or copperas, or sulphuric acid, or the magnesium compounds in Stassfurt potash salts, have been published. The significance of these additions has already been set forth; but, with the exception of the actual stable-floor or standing-room of the animals, it does not appear that much ammonia is lost from cow-manure during the ordinary conditions of fermentation. It is a fact constantly to be insisted upon, that the risk of losing ammonia from manure applies more particularly to dry heaps. Practically next to no ammonia is lost from manure-heaps which are kept in a moist condition. Indeed, according to Dehérain, it happens in heaps of manure (dung, urine, and straw) which are kept properly moist, that much of the ammonia, that forms at first from the decomposition of urea, is changed by the action of ferment organisms into compounds of nitrogen, which are very unlike the ammonia from which they were derived. He noticed also that these organic nitrogen compounds dissolve in no inconsiderable quantity in the alkaline dung-liquor. During the actual fermentation, some of the nitrogen from the ammonia may be lost as free nitrogen gas, especially from those parts of the heap to which the oxygen of the air has easy access; but the loss of ammonia as such is usually extremely small, so long as the heap of manure is kept moist.

The less moist horse-manure, when left to ferment in loose heaps, gives off, as every one knows, large quantities of ammonia. For the sake of the object-lesson, German farmers have occasionally led air from a horse-stable over or through porous materials saturated with muriatic acid, and have evaporated to dryness the solution of ammonium chloride thus obtained, in order to exhibit the concrete substance. I have myself seen, at a cattle-show in Prague, a massive block of ammonium chloride which had been obtained in this way.

It has been noticed in the experiments of Jentys, that even in the case of horse-dung, the loss of ammonia occurs chiefly during the early stages of the fermentation, and that after a short time, the loss of ammonia from solid excrements may amount to little or nothing. In experiments on fresh dung, he found that something like one-tenth of the total nitrogen passed into the state of ammonia in the course of a month, while nine-tenths of the nitrogen was found to be in organic forms, some of which appear to be not readily assimilable by plants. In the case of mixed solid and liquid excrements, however, the loss of ammonia was more considerable. It is a matter of familiar observation that from cow-manure, and the ordinary mixed manure of the farmyard, so long as it is kept moist and compacted, no very pronounced fumes of ammonia arise. Voelcker, in his experiments on mixed farm-manure, found that free ammonia was disengaged only when the dung-heaps were in a state of active, hot fermentation. No ammonia was given off when the heaps of manure were quite cold. As he remarks, "In the interior of large heaps the heat is often very great, — the thermometer rising to 120° or 150° F., — and it is from this part of the heap that ammonia is given off when manure is forked over. But so long as the heap is left at rest, the ammonia at its interior does not escape into the air, because it is restrained by those portions of the manure which are kept cold by the surrounding air. The external cold layers of dung-heaps act as a mechanical and chemical filter with reference to the ammonia. . . . Dung-heaps that have been placed in a field cease to give off ammonia after a short time when settled down to a firm mass, but on turning such heaps, a very powerful and pungent smell is perceptible. Each turning of a manure-heap thus is attended with a certain loss of ammonia that escapes from the heated manure. But at the outside of an undisturbed heap which has had time to consolidate no ammonia is perceptible; even delicate red litmus paper is not altered in the least." Dehérain also, on collecting and analyzing the gases taken from the interior of moist heaps of manure, could not detect any appreciable quantity of ammonia.

Voelcker urges that, when ammonia forms in heaps of well-kept farm-manure, through the fermentation of nitrogenous organic matters, humic acids are produced at the same time, which combine with the ammonia, and fix and hold it against loss through volatilization. These humates and ulmates of ammonia are soluble in water, and are readily leached out of the heaps by rain. To the presence of such compounds, dung-liquor owes its dark brown color. In consonance with this view, Kellner has observed that during the fermentation of moist organic matter, i. e. during such fermentations as occur when green plants are packed in silos, considerable quantities of ammonia are formed, and that this ammonia is held in combination by organic acids, both volatile and non-volatile, which are formed at the same time. Meanwhile, no free nitrogen gas is exhaled, at least not in the case of fermentations due to the presence of the lactic ferment occurring out of contact with the air. An exception to this rule occurs when the plants happen to contain nitrates which are deoxidized in the silo with loss of nitrogen gas.

With regard to the notion that chemical agents should be applied to manure-heaps, "to hold the ammonia," Voelcker says, as there is, practically speaking, no free ammonia in either fresh or rotten farmyard-manure, the addition of such chemical agents as change volatile compounds of ammonia into non-volatile combinations is unnecessary and useless, in so far as this particular action is concerned. It is but fair to add that the same conclusion had been reached and proclaimed by Boussingault, long before the time of Voelcker's research.

Ashes of Dung.

It is evident enough, from the foregoing statements, that, for cold and temperate climates, and for most crops, the nitrogen in dung and urine is by far the most important constituent of farm-manures, i. e. economically speaking. In an experiment tried by Boussingault, in Eastern France, the ashes left on burning 22 tons of farmyard-manure were applied to one acre of land, which had been somewhat impoverished by cropping, while a contiguous acre of similar land was dressed with 22 tons of the manure itself. Oats were sown on both the acres, and there was harvested from the land dressed with ashes 4 times as much grain as had been sown, while the dunged land yielded 14 times as much grain as had been sown.

In a subsequent chapter, further evidence will be set forth to show why it is that farmers should take special pains to preserve the dung-nitrogen carefully, and to apply it understandingly. But it is true, nevertheless, that in some countries — notably India and certain marsh-land districts in Southern France — only the ashes of dung are applied to the land. Even in the time of the Romans, as Pliny tells us, the farmers of some parts of Italy were in the habit of burning dung for the sake of its ashes, which they preferred to the dung because the ashes are light and can readily be transported and applied. The ashes were not used indiscriminately, however, by the Romans on all kinds of soils, nor were they employed for promoting the growth of shrubs or of some of the cereal grains. But in India, even at the present time, it is customary, almost everywhere, to knead into cakes, together with broken straw, all the cow-dung that can be procured, and to dry these cakes in the sun for fuel. On asking, near Lucknow, why they did not reserve their cow-manure for the land, Mr. Caird was answered as follows: "What would you? We cook our food with it, we warm our bodies with it, and then we use the ashes as manure." In Egypt, also, as in India, cow-dung is made into cakes and dried to serve as fuel for cooking food.

It is noticeable that the use of dung-ashes prevails specially in hot countries where nitrification is particularly rapid; and that usually the ashes are applied to soils rich in humus. Hitherto, travellers appear to have paid very little attention to the question, whether or not the dung-ashes are commonly applied to leguminous crops. The following experiment, made by Mr. Robertson, director of the experimental farm at Sydapet, near Madras, for the purpose of comparing the fertilizing power of cow-manure with that of the ashes of a similar quantity of cow-manure which had been burnt as fuel, has been reported by Caird. Upon the first of three adjoining plots of land, 3,150 lb. of cow-manure were put; the second plot received 130 lb. of ashes, i. e. the amount obtained on burning 3,150 lb. of cow-manure, while no fertilizer was put upon the third plot. All the plots were sown with cholum (a tall, coarse variety of millet), to be mown as a green crop, and they were treated alike, excepting as regards the manure. The amounts of fodder obtained from the first and second cuttings of cholum are given in the following table: —

	Plot 1. Cow-Dung.	Plot 2. Ashes of Cow-Dung.	Plot 3. No Manure.
First cutting, lb.	4,058	4,368	3,140
Second cutting, lb.	1,680	1,176	896
Total, lb.	5,738	5,544	4,036

CHAPTER XX.

COMPOSTS.

In discussing methods of preserving farmyard-manure, as in the preceding chapter, the question of compost-making naturally presents itself, and attention is called forcibly to the consideration of several well-known facts which bear upon this subject.

It is a matter of old observation, that, if some kinds of peat be mixed with fresh stable-manure in the proportion of two or three loads of the peat to one load of the dung, and the mixture be then allowed to ferment, there will be obtained a compound as efficient, load for load, for many fertilizing purposes, as pure stable-manure. The observation has repeatedly been verified both in Europe and in this country, and the fact itself cannot be gainsaid.

Doubtless several causes conspire to produce the stated result. The fertilizing qualities proper to the peat are utilized, and the fermentation which it undergoes conduces to that end. The power of the peat to absorb and hold liquids comes into play of course, and it is to be noticed also that the presence of peat in the mixture may cause the manure to ferment to better advantage than it would have done by itself. This thought not only bears directly upon the question of preparing composts with dung, but, as has already been suggested, it is most intimately connected with the problem how best to preserve manures.

Composting saves Manure.

As matters actually stand, there appears to be little doubt that the results of practical experience teach that, in many situations, a larger proportion of the useful ingredients of dung and urine can be saved by mixing these substances with comparatively large quantities of peat, or loam, or clay, or straw, or leaves, before fermentation has set in, than by suffering the excrement to ferment in the barnyard by itself. Mention has already been made of the fact that horse-manure may be preserved by mixing it with enough moist peat or loam to check the action of the fungus which causes "fire-fanging." But in such admixture may be seen the beginnings of the so-called process of composting, and it may be said, truly enough, that composting is practised in some sort wherever loam and peat, or even straw or leaves are used for bedding animals.

It may be well at this point to recur to the practical experience of farmers, and to cite some new examples from it, though it needs to be said, at the start, that many farmers are strongly opposed to the use of loam bedding in cow-stables. Their objections are based, however, mainly upon the dirtiness of the earth and the labor of handling it; the criticism does not depend upon chemical considerations, and most farmers seem to agree that cow-manure may be very well preserved by the earth. Some farmers have claimed, indeed, that cows can be kept clean enough for all practical purposes by using straw for bedding them, in conjunction with the loam; and they hold that the trouble thus taken is more than paid for by the comfort of the animals and the increase of manure. Probably peat or loam covered with sawdust would serve a good purpose.

Loam for bedding Animals.

In Egypt, on the Nile Delta, in March, 1879, when the river was low, Caird noticed that "Manure is collected by carrying in earth to bed the stalls in which the cattle are placed at night, and where they receive forage. Nothing is allowed to run to waste."

But, as is well known, most of this manure is dried to serve as fuel.

Rotenhan, in Germany, describes as follows his method of bedding 100 head of neat cattle during the winter months on nothing but loam. A line of heavy joists is laid down and firmly fastened to the floor behind the animals, i. e. between them and the gangway, in order to hold the loam in place. The whole of the standing-room between these joists and the cribs is filled with a layer of dry loam, the depth of which is as much as 8 or 10 inches at the rear, i. e. next the joist. In this way a horizontal layer of earth is provided for the animals to stand upon.

Three or four times a day the dung, with whatever loam has become moistened with urine, is scraped out and left in little heaps behind the animals, while the holes and irregularities of surface that have been made by removing the loam are filled up or smoothed off by scraping into them earth from other parts of the bed. Once a day the heaps of dung and loam are thrown out into the yard. At the end of every fortnight or three weeks, the standing-room is cleaned out and a new layer of loam laid down in it, for the reason that the continual trampling of the cattle impacts the earth so firmly that it can no longer absorb urine as quickly as is desired.

In order that the animals may be kept clean, dry, and healthy in this way, it is essential that the earth should be dry. Sandy loam does well, and so do loams rich in humus, but clays are bad. The more humus there is in the earth, so much the larger will its power of absorbing water be, and so much the smaller quantity of it will be required. The use of dry peat for this purpose is not uncommon. Rotenhan carted the loam in autumn and kept it under a roof. Each of his animals appears to have used as much as one or two two-horse loads of the loam every month. Heiden computes that, for 1000 lb. of live weight, cows will need some 180 lb. of loam (2½ cubic feet) per diem in order that they may stand tolerably dry.

Another way of applying the earth is cited by S. W. Johnson in his essay on "Peat and its Uses." Mr. Holbrook of Brattleboro', Vt., every morning before cleaning the cow-stable, throws a bushel-basketful of peat upon the dung behind each of the animals. The peat absorbs completely the urine and other moisture of the manure, which is held in a water-tight trench behind the cattle, and the warm mixture soon enters into fermentation when thrown from the stable. Mr. Holbrook, looking at the matter as a making of manure from peat rather than as a saving of manure by peat, maintains that "much more peat can be well prepared for use in the spring in this way than by any of the ordinary methods of composting."

Compost-Heaps.

Many farmers prefer to make their compost in heaps. A common plan is to lay down a bed of peat six or eight feet wide and a foot or so thick, to cover it with a layer of dung of somewhat less thickness, followed by another layer of peat, and so on, until the heap has become three or four feet high. Various proportions of peat are employed by different farmers in the preparation of these compost-heaps. The ordinary range is from 1 to 5 loads of peat to 1 load of manure, according to the kind of peat and the quality of the dung. Rich dung from stall-fed horses or fatting cattle will bear more peat than that from animals less highly fed. If there be much straw or other litter in the manure, less peat will be added to it than if the dung were clear. Generally speaking, the farmer would naturally tend to use more or less peat in composting, according as his land is light and sandy and in need of humus, or already charged with that substance.

The practical rule is to use no more peat "than can be fermented thoroughly by the manure," though it may perhaps fairly be questioned whether this rule should be applied rigidly in all cases. Possibly a better rule would be not to use enough peat or other admixture wholly to prevent the dung from fermenting.

In case the dung were free from long litter, it is possible, though not probable, that it might be still better in some cases to mix as much peat with the dung as would just prevent it from fermenting, though it might perhaps be difficult to accomplish this purpose. There would be a certain risk withal, if peat enough were used to prevent the dung from fermenting in the usual way, that the heap might proceed to ferment in some other unusual and hurtful way, and so destroy itself.

Probably there are many cases where it would be well to keep dung and urine in the barnyard fresh and raw by means of peat, if that could be done without too much labor, even if the peat should remain unfermented, though it might be impracticable to accomplish this result unless the mixture were to be put in a silo, and if a silo were to be used the peat might well be dispensed with altogether. Hence the second rule suggested, not to use enough peat wholly to prevent the dung from fermenting, may possibly be the best of the three. From what has been said already under Farmyard-Manure, it is plain that, in order that peat or other litter shall act to preserve manure, the mixture must be kept moist and firmly compacted. The risks which attend the free admission of air to such materials will be considered more fully hereafter.

Practically, the amount of peat to be used must always be determined by considerations of economy relating to the particular farm on which the compost is to be made. So long as peat can be hauled at small cost by men and teams belonging to the farm, at times when work is slack, and no more profitable way of expending the labor can be found, it will be well to haul it, provided that the cost of labor to be expended in preparing the compost and in distributing the bulky material in the fields is less than the cost of obtaining an equivalent quantity of commercial fertilizers would be.

Composts require much Labor.

As regards weight and the amount of water which it can hold in its pores, swamp muck differs less from farmyard-manure than might be supposed. As tested by Henry Stewart, a cubic foot of soft, wet muck, such as could be cut like butter, although it was somewhat fibrous, weighed, as taken from the bog, 67 lb. When dried in warm air, it gave off 83 % of water. At the same time, Stewart found that fresh horse-manure, free from litter, when pressed tightly into a box with a rammer, weighed 64 lb. to the cubic foot; and that fresh cow-manure, free from litter, and similarly packed, weighed 66½ lb. to the cubic foot. Cow-manure taken from the bottom of a heap, where it was saturated with urine and had become partly rotted, weighed 70¼ lb. to the cubic foot.

On the other hand, it must always be remembered that the commercial fertilizers are concentrated and compact, and that the cost of distributing them is small. It is true, in fact, that the widely extended use of these fertilizers in recent years, or rather the ability to procure them readily, has caused composts to fall into disrepute. Compost-heaps are established much more rarely nowadays in New England than they were formerly; though the remark, as quoted by Professor Johnson, that "the composting of muck and peat with stable and barnyard-manures is surely destined to become one of the most important items in farm management throughout all the older States," is probably still true of a land of small proprietors, for whose labor there is at times no profitable outgo. It can hardly be accepted, however, as it stands, with regard to farms worked by hired labor for the sake of money profit only. In the immediate vicinity of a city, moreover, it would usually be more profitable to expend labor in hauling out horse-dung or night-soil than in building compost-heaps.

Composting saves Nitrogen.

As has already been intimated, there is still much to be learned with regard to the chemical changes which occur when manures or composts ferment. It is to be presumed, of course, economically and practically speaking, that no process of fermentation can do more than change the things which are originally present in the dung or in the peat into new forms. It is not to be supposed that enough nitrogen can be absorbed from the air and fixed in a single compost-heap to be of much practical significance. Yet there are many peats, which long experience has shown to be good for making composts, that appear at first sight to contain no very large quantity of matters useful for vegetation. A peat of excellent reputation, analyzed by S. W. Johnson, was found to contain, when in the air-dried state, three per cent of ashes, more than half of which was mere sand, and one and a half per cent of nitrogen, upon which, of course, the chief value of the material must depend. This peat was composed almost entirely of carbon, hydrogen, and oxygen, neither of which elements can be classed among fertilizing substances; whence it is plain that, excepting as regards its nitrogen, no very large amount of plant-food can be got directly from a peat even so good as this one.

But in addition to the nitrogen which is contained in them, there are several ways of accounting for the utility of peat. First of all, it is to be noticed that peat, at least when in its crude state, is an antiseptic or germicide agent of considerable power. Sour peat will kill the micro-organisms that cause fermentation, or prevent them from thriving, so that active fermentation could hardly occur in presence of any considerable quantity of it. This fact goes far to explain how it is that peat, when used for bedding animals or for absorbing their liquid dejections, serves so well to preserve the manure, i. e. by delaying fermentation.

Moreover the humic acids in peat, even that which has been thoroughly weathered, are highly effective agents for absorbing ammonia. In this respect, Professor Johnson found that a swamp muck from the neighborhood of New Haven was capable of absorbing 1.3 % of ammonia, while ordinary soil absorbed only from 0.1 to 0.5 %. Heiden also noticed that a light, fibrous, crumbly peat used as litter in cow-stables, which contained when air-dried 0.37 % of ash-ingredients and 93 % of organic matter, of which 11 % was humic acid and 0.64 % was nitrogen, was capable of binding 1.6 % of ammonia. He urges that such peat would be excellent for composting with night-soil, and that the product would be a good manure for light lands.

Koenig also has shown by an elaborate research that peat-moss and peats of various kinds can absorb and fix large quantities of ammonia from solutions of the hydrate and carbonate and phosphate, i. e. from compounds of ammonia with weak acids. The reactions are very different, however, as regards solutions of the sulphate, chloride and nitrate of ammonia, and there are many peats which can absorb but little ammonia from solutions of these salts. On leaching the peats with hot acids in order to remove most of their basic constituents, it appeared that their absorptive power was diminished in respect to the sulphate, chloride and nitrate of ammonia, but that the leached peat could fix as much ammonia as the natural peat (or even more) from ammonia water, carbonate of ammonia and phosphate of ammonia. It was noticed that even paper pulp absorbed some ammonia from ammonia water, and a little from carbonate of ammonia, but none from a solution of chloride of ammonium. Koenig attributes this fixing power in part to chemical action and partly to physical adhesion, but Van Bemmelen is disposed to attribute it to the binding action of colloid humus.

The results given in the table were obtained by Detmer in experiments where ammonia gas was passed through tubes charged with mixtures of peat and sand: —

The Mixture contained		There were absorbed Grams of Ammonia.	Each 100 Grams of the Peat absorbed Grams of Ammonia.
Per Cent of Sand.	Per Cent of Peat.		
100	..	0.093	...
90	10	0.187	2.06
80	20	0.311	2.37
70	30	0.654	3.80
60	40	0.996	4.70

50	50	1.090	4.18
40	60	1.152	3.72
30	70	1.245	3.48
20	80	1.339	3.30
10	90	1.494	3.30
..	100	1.712	3.42

Peat-Moss as Bedding.

In some parts of Germany a fibrous variety of peat — the so-called peat-moss — is used even for bedding horses, usually by itself, though in some cases a thin layer of straw is spread upon a three or four-inch layer of the peat-moss. It is said that any friable peat that is fibrous enough not to become muddy when wet admits of being used in this way. In recent years, large quantities of this brown peat-moss fibre have been exported from Germany to England and to the United States to be used for litter, as a substitute for straw. This peat-fibre absorbs a much larger amount of water than straw can, and the humic acids in it act both to hinder the fermentation of urine and to hold the ammonia which finally results from its decomposition.

It is urged, among other merits of the peat-moss, that horses will not eat any of it, that it is easy to keep the animals clean, and that hardly any odor of ammonia need be perceived in stables where it is used. Indeed it seems to be admitted that stables and cow-stalls littered with peat-moss are sweeter that those littered with straw. English experience goes to show that one ton of the peat-fibre used as litter may do the work of nearly two tons of straw. According to Arnold fine peat-fibre will absorb some 7.5 to 8 times its weight of water, while straw and sawdust are able to take up only about 3.5 to 4 times their weight. Petermann found that 100 lb. of peat-moss was equal, for purposes of bedding animals, to some 210 or 225 lb. of straw. It is important, however, that any excessively wet parts of the bed of litter should be replaced without much delay with fresh peat-moss for the very fact of the high absorptive power of the peat, taken in connection with its dark color, makes it a less cleanly bedding than straw, and less dry also, unless pains are taken to keep it in good order.

Experiments made in Paris by the Omnibus Co. went to show that, when used as litter, 3.3 kilos. of peat-fibre served as good a purpose as 3.5 kilos. of sawdust, or 4.8 kilos. of straw. The amounts of manure produced per day and per horse were, with the peat 10 to 11 kilos., with sawdust 12 to 13 kilos., and with straw 25 kilos.; and the percentage amounts of nitrogen in these manures were 0.68, 0.45 to 0.49 and 0.51 respectively.

According to Arnold, peat-fibre absorbs moisture so evenly that, in so far as this point is concerned, it would make little difference whether a given quantity of the material were to be strewn all at once in the horse-stall, or by 3 or 4 instalments. But in order to avoid odors it is necessary to spread no more than a thin layer of the peat and to replace it as soon as it has become moist. Since the peat occupies much less space than straw it is specially well suited for use in stables where the dung-pit is small.

Analysis No. I in the following table is by Arnold; No. II is by Voelcker. In most instances, the materials were air-dried. No. III is by Wattenberg. 100 parts of No. III absorbed 860 to 895 parts of water, while rye-straw absorbed only 390 parts, and spruce sawdust 368 parts. No. IV is by A. Mayer at Wageningen, in Holland.

	I. %	II. %	III. %	IV. %
Water	14.50	13.00	18.90	20.00
Organic matter . . .	84.29	85.00	....	78.90
Ashes	1.21	2.00	0.87–1.33	2.10
Potash	0.08	....	....	0.04
Phosphoric acid . . .	0.08	....	....	0.04
Total nitrogen . . .	0.64	0.60	0.49	0.80

Fleischer tested peat-moss, for bedding cows, as compared with rye-straw chopped to five-inch lengths, and found that 3.5 kilo. of the peat-moss, per head and day, or 4.6 kilo. of straw, were competent to absorb all the urine. There was produced meanwhile, per head and day, 51 kilo. of the peaty, and 55 kilo. of the strawy manure. In other trials, 3.5 kilo. of peat-moss and 4.3 and 5 kilo. of straw were expended per head and day, and 54.5, 53.4, and 57 kilo. of manure were produced respectively. Analysis of the manure showed that the peaty product contained more easily soluble nitrogen compounds than the strawy manure contained, and it was calculated that a stable of 10 cows bedded with the peat could retain, in a year, 140 kilo. more of the easily soluble nitrogen compounds than would be retained by the straw. On applying the two kinds of manure to oats, rye and potatoes in the field, it appeared that on light land the peaty manure gave rather better crops than the strawy manure. The better nitrogenous condition of the peaty manure was shown by the fact that the leaves of the peat crops were darker colored than the others, and of more luxuriant growth.

Borntraeger has noticed that stable-manure of which the light, porous peat-moss is a constituent part nitrifies much more rapidly than manure with which a more compact peat has been admixed. In experiments by Muntz and Lavalard, mangolds were dressed with 35 tons to the acre of manure from stables where straw and peat-moss had been used respectively, and rye was grown the next year without any additional manure. There was harvested, lb. per acre, from the —

	1st Year. Beets.	2d Year. Rye.
Strawy-manure	31,680	909
Peat-moss-manure	38,720	1,086

Hitier, also, made trials with sugar-beets on a strong, clayey soil. The same quantity of strawy and of peat-moss manure was used on each plot, and the manure was re-enforced, in both cases, with a heavy dressing of ground phosphate rock. There was harvested, lb. per acre, from the —

	Beets.	Sugar.
Strawy-manure	27,960	4,016
Peat-moss-manure	34,144	4,898

An English observer, Murray, has urged that the action of this manure, both on grass and tillage land, is quick but not of long duration, as there is little appreciable result after the second year.

Composting corrects Acidity.

It is probable that one important step in the curing of peat in dung composts is the neutralizing of the sourness of the peat through the alkalinity of the manure, just as in composts made with lime or with potash the acidity of the peat is neutralized. There are English experiments which show not only that peat is really effective for holding ammonia, but that it is decidedly better, for this purpose, than charcoal made from peat. In one of these trials, 300 grm. quantities of the peat and the charcoal were mixed with half-ounce portions of urine and left to stand over sulphuric acid, under bell-glasses, during 5 days, and it was found that, while no ammonia escaped from the peat, as much as 0.3 grm. of it volatilized from the charcoal and passed over into the sulphuric acid.

From some analyses made by S. W. Johnson, it would appear that peat can absorb and retain nitrogen from manures in some other form than that of ammonia. Thus a peat which in the crude air-dried state contained only as much nitrogen as would amount to 0.58 % of ammonia, was found to contain nitrogen equivalent to 1.15 % of ammonia after it had lain under the flooring of a horse-stable for some time, where it had been partially saturated with urine. Some of the same kind of peat, after having been composted with fish, was found to contain nitrogen corresponding to nearly 1.31 % of ammonia. It would appear in these cases, not only that some ammonia had been absorbed, but that either amids or other organic compounds of some kind had been formed by the decay of the nitrogenous constituents of the dung, the urine, or the fish. The amounts of nitrogen just mentioned seem large, in view of the fact that stable-manure usually contains considerably less than one per cent of this element. And if it be true, as would seem clearly to be the case, that peat has the power to absorb and hold even as much as one-half of one per cent of its weight of nitrogen when composted with manure, the fact is one of great importance.

Perhaps the best way of illustrating the significance of the nitrogen in peat-composts will be to recur yet again to the well known practical fact, that the application of a very small quantity of active nitrogen is often sufficient to insure the growth of large crops. A dressing of 250 to 400 lb. of Peruvian guano to the acre gives only from 50 to 70 lb. of ammonia, even if the guano be of super-excellent quality (15 % N); and in order to obtain as much active nitrogen as this, there would need to be applied to the land some 5,600 lb. of composted peat that contained 1.25 % of ammonia. But in actual farm practice, an ordinary rate of applying such compost is ten cords to the acre, and it is fair to suppose that each of these cords may weigh 4,000 lb. at the least.

It is evident enough that the inert matters used for composting with dung and urine may sometimes act to check excessive decay and to prevent fermentations from becoming too hot and too violent. But it is a question still to be studied, whether matters rich in cellulose and other carbohydrates, such as straw, for example, may not in some way act chemically, during their slow decay, to shield a portion of the nitrogenous constituents of the urine or the dung. That there may be possibly some grains of truth in this idea is suggested by the fact that the humus formed through the decay of vegetable matters is, in many cases, richer in nitrogen than the materials from which it was derived.

Curing of Peat.

Thus far the argument has been based almost wholly on the preservation of manure, and very little has been said of the improvement of peat, or of any other substance used for composts, at least not directly. But enough has been said indirectly to make it evident that much more remains to be urged on this side of the question. In fact, there cannot be any doubt that peat and loam, and leaves and straw, and many other organic matters which are comparatively inert in their natural or crude state, become more or less powerful manures after they have been fermented.

It is an observation only too familiar, that heaps of decaying manure left in contact with wooden structures — such as the side of a barn, for example — "make the wood rot." So, too, the nets of fishermen, when besmeared with slime and scales, will quickly ferment and decay unless they are heavily salted, or in some other way protected from the action of the ferment with which the animal matter was charged. To all intents and purposes, "composting" occurs in both these instances. The boards of the barn and the twine of the net, like the peat or the straw in an ordinary compost-heap, undergo decay because their components soon become involved in the fermentation which was at first confined to the fish-slime or to the manure. To take a still more familiar example, a fence-post set in the ground speedily rots because the wood is "composted" by the action of organisms which are contained in the decaying loam around it, — unless indeed the post has been made of some specially refractory wood, or has been tarred or otherwise smeared or saturated with a preservative agent which shall repel the micro-organisms.

Composting disintegrates Vegetable-Matter.

Mention has already been made of the fact that a good part of the constituents of straw remain bound up, and unavailable as plant-food, until the organization of the straw is destroyed; and the same remark will apply of course to all organized vegetable matters, such as leaves and stalks, and twigs or chips of wood. But by causing these inert matters to ferment, by mixing them with dung, or blood, or fish, or flesh, or any other putrescible or easily fermentable matter, their organization is quickly destroyed, and some part of the nitrogenous matters within them will be made fit for the support of crops. Even the inorganic constituents of the vegetable matter may become more readily available by composting. Just as in the fermentation of bone-meal, while the conversion of ossein to assimilable products is the chief desideratum, it may still fairly be inferred that the phosphate will be laid bare, and made more readily accessible to solvents and to the roots of plants than could have been the case if the particles of bone had not been decomposed and disintegrated.

Analogy, drawn from practical experience with fermented bone-meal and fish-scrap, points to the conclusion that peat and straw, or other litter, may often be greatly improved when subjected to appropriate fermentation; and Pagel has shown by methodical experiments that fermentation is really an efficient means for improving the inert nitrogen in many organic matters. He finds that much of the insoluble organic nitrogen is thus converted to soluble forms. But the fermentation must not be too violent, lest much of the nitrogen be wholly lost.

It is to be noted that, in numberless instances, small quantities of so-called toxines or ptomaines are known to be formed among other products of the decompositions brought about by the micro-organisms to which fermentations are due. These toxines are soluble nitrogenous substances, akin to the alkaloids found in certain plants, and although they may not themselves be fit for feeding plants, their formation suggests the idea that there may perhaps be formed at the same time other analogous, organic nitrogenous matters which are really useful as fertilizers.

In Pagel's experiments one set of boxes were charged with 100 lb. or more either of bone-meal or of fish-guano that had been intimately mixed with some 35 or 40 quarts of either ox-urine or dung-liquor, and the materials were then left to ferment; while to another set of boxes, similarly charged, 10 % of gypsum was added, and incorporated with the materials. The results of these trials are given in the table.

Materials used.	Per Cent of original Nitrogen that became Soluble.	Per Cent of original Nitrogen that went to Waste.
1. Fish-guano, urine, and gypsum (moist)	40.4	. . .
2. Same as No. 1, without gypsum (very moist) . . .	48.3	. . .
3. Bone-meal, dung-liquor, and gypsum, very moist at first, afterwards dry	46.6	4.7
4. Bone-meal and urine (moderately moist)	80.0	39.2
5. Fish-guano and small amount of dung-liquor, incompletely moistened	42.5	4.3

From No. 3 it appears, as has often been shown by other experiments, that gypsum hinders the waste of nitrogen during fermentation. In No. 5, but little dung-liquor was added in the beginning, in order that the fermentation might be weak and slow. Pagel urges that, in order that a fermentation may be regarded as proper, much heat must be developed by the materials. A thermometer thrust into the fermenting mixture should mark more than 100° F. The completion of the fermentation is indicated by the diminution of the high temperature. A considerable fall of temperature shows that action has ceased. But a new fermentation may be excited by forking over the heaps of materials, and moistening the dry places, best with dung-liquor or urine. Too large a proportion of the urine, or other fermenting material, should not be used at first, lest violent action should occur. For the particular case of bone-meal, 25 or 30 quarts of dung-liquor to 110 lb. of the meal is considered to be a good proportion.

These Fermentations are analogous to that of Manure.

More or less time is required for the completion of such fermentations, according as heat is developed slowly or speedily at first, and according as the heaps of material are large or small. In general, 3 or 4 weeks will be sufficient for the completion of the process, when materials such as bone-meal or fish-scrap are fermented. These results corroborate the observations of Voelcker on the decay of farmyard-manure. In his own words: "In the first stage of decomposition, i. e. during the active fermentation of mixed dung and litter, the constituents of the manure are rendered more and more soluble, so that up to a certain point the amount of soluble organic matter increases in farmyard-manure. Hence a larger proportion of organic matter is found in the liquor that drains from a fresh manure-heap in an active state of fermentation, than in the liquid from an old well-rotted heap. But when active fermentation in manure-heaps becomes gradually less and less energetic, and finally ceases, the remaining fermented manure is subject to that slow but steady oxidation which has been termed eremacausis. To this process of slow oxidation, all organic substances are more or less subject. It is a gradual combustion, which terminates with their final destruction."

It should be borne in mind that one essential condition for the fermentation of composts is that the materials should be kept moist. In times of drought it might be well to drench the compost-heap occasionally with barnyard-liquor, or with water. It is worthy of remark, also, that Dietzell has found that the loss of free nitrogen gas from fermenting organic matters may be prevented by adding to the materials some precipitated phosphate of lime.

Straw Compost.

On farms in Sweden belonging to the crown, where legal restrictions prevent the sale of straw, the excess of this material has sometimes been composted by drenching 6 or 8 feet high heaps of it with water, in which powdered rape-cake has been soaked and stirred. The moist heap, loosely covered with earth 4 or 5 inches deep, is left to ferment for a month, and is then forked over and again drenched with the rape-cake liquor. The heap is then left to itself until hauled out as manure. From 30 wagon-loads of straw and 3 cwt. of rape-cake, Bergstrand obtained nearly 30 wagon-loads of "manure" in the course of two months and a half. On comparing the product with stable-manure, by means of analysis, he obtained the following figures: —

	Straw Compost. Per Cent.	Ordinary Farm-Manure. Per Cent.
Water	74.36	79.30
Organic matter	15.63	14.01
Ashes	10.01	6.69
Nitrogen	0.23	0.41
Phosphoric acid	0.10	0.20
Potash	0.17	0.50

Some of the changes which straw undergoes when composted have been studied by Hébert. A quantity of powdered straw was moistened with solutions of carbonate of potash and carbonate of ammonia, a small quantity of barnyard-liquor was added, in order to excite fermentation, and the mixture was left to itself for 3 months at a temperature of 131° F. At the end of this period it appeared that the straw had lost half its weight, and that of the cellulose alone 56 % had disappeared. While the original straw had contained 0.39 grm. organic nitrogen, and the added liquids had contained 2.64 grm. of ammonia-nitrogen, there was found at the close of the experiment 0.24 grm. of organic nitrogen in the straw, while in the liquid there was 0.40 grm. of ammonia-nitrogen, plus 0.96 grm. of organic nitrogen. It appears that a part of the ammonia had been changed to nitrogenous organic compounds, while about 47 % of the original ammonia-nitrogen was lost.

De Vogüé, also, in studying the composting of straw with ammoniacal liquor from gas-works, took pains to saturate 2,500 kilo. of straw with 9,000 litres of the liquor, and noticed that the violent fermentation which soon set in culminated on the 13th day, when the temperature of the heap was higher than 212° F. Much vapor of water was given off, as well as carbonic acid. Analysis showed that the gases evolved contained 32 % of carbonic acid, but no more than traces of oxygen. The carbonate of ammonia of the gas-liquor acted on the organic matter of the straw to decompose and dissolve it, and the ammonia entered into combination with the humic products of the reaction, so that a black liquid oozed from the bottom of the heap. It was observed that, beside the carbonic acid formed through oxidation of the straw, some part of that evolved from the heap came from the decomposition of the carbonate of ammonia by the humic acids which resulted from the decomposition of the straw.

After the first fortnight the activity of the fermentation gradually lessened, though carbonic acid continued to be given off in diminishing quantity during 4.5 months, when the operation was regarded as finished. The contents of the heap then looked like half-rotted, black manure, and it was found that they had decreased in weight to the extent of 4,200 kilo., i. e. a little more than one-third of the weight of the original materials had been lost. Analysis of a sample taken from the heap on the 33d day of the experiment showed 80 % of water and 20 % of dry matter. The undried compost contained at that time: —

0.067 % of ammonia-nitrogen, volatile at 212° F.
0.130 % of " " non-volatile at 212° F.
0.483 % of organic nitrogen,

0.680 % of total nitrogen,

which is an amount rather larger than that found in most samples of first-rate farmyard-manure.

The Fermentations of Sugar.

Perhaps some idea of what happens in the fermentation of straw — as well as of peat, or wood, or any other composted vegetable matter — may be gained by considering some of the reactions which occur in the fermentations of sugar. Grape-sugar ($C_6H_{12}O_6$) contains 40 % of carbon, 6.67 % of hydrogen, and

53.33 % of oxygen, and when it is subjected to the action of the yeast-plant, it breaks up for the most part into alcohol and carbonic acid,

$$C_6H_{12}O_6 = 2\ C_2H_6O_2 + 2\ CO_2,$$

although small quantities of some other substances, notably glycerin and succinic acid, are formed as the result of subsidiary reactions. On the other hand, when grape-sugar is subjected to the action of the butyric ferment, it may break up into butyric and carbonic acids, while hydrogen gas is evolved: —

$$C_6H_{12}O_6 = C_4H_8O_2 + 2\ CO_2 + H_4.$$

But in like manner, cellulose ($C_6H_{10}O_5$), which constitutes the outer coating or wall of most vegetable cells, may break up into substances simpler than itself under the influence of one or another ferment, and this remark will apply to straw and wood, and all other vegetable matters. Pure cellulose contains 44.44 % of carbon, 6.17 % of hydrogen, and 49.39 % of oxygen, while the composition of wood has been found to range from 46 to 54 % of carbon, 6 to 6.65 % of hydrogen, and 39 to 47 % of oxygen, together with some nitrogen. Sawdust contains about 1 % of nitrogen, while young twigs, with their leaves, may contain 2 or 3 % of it. As a rough approximation, the composition of wood has sometimes been represented by the formula $C_{34}H_{48}O_{22}$, and that of some kinds of peat has been written $C_{20}H_{22}O_8$. But from the analogy of sugar it is easy to conceive how the constituents of wood or straw may be broken down by fermentation, and it is to be presumed that a part of the nitrogen of the woody fibre may be changed either to ammonia or to some other compound which can afterwards be nitrified more readily — when exposed to fit conditions — than the original nitrogenous matter of the wood could have been nitrified.

Peat-Composts.

In the preparation of peat-composts, dung and fish are the materials commonly employed to excite fermentation: but urine, or guano, or the dung of fowls, would serve the purpose excellently. Blood is objectionable, because of the horribly offensive odor which is exhaled by composts prepared with it. It might not be easy to say just what the substances are which smell so offensively, but there is every reason to believe that they have no agricultural significance. There is no greater fallacy than that which gauges the worth of a manure by the stench the manure emits.

By the process of fermenting, time is gained; the organization of the vegetable matters is broken down in a few weeks or months in the compost-heap, instead of resisting decay for a long time, as would be the case if the matters were left to themselves. This point might be illustrated by reference to an oak stump. Left to itself, the stump long resists decay, though the mould which finally results from its decay is rich in plant-food. But the decay could soon be effected by reducing the fresh stump to the condition of saw-dust, and fermenting this saw-dust in any appropriate way. Another striking illustration was offered by the former use of woollen rags in European agriculture. These rags, as has been shown already, contained 12 to 14 %, sometimes even 16 or 18 %, of nitrogen, but they decomposed so slowly in the soil that their action was felt on good moist land for 7 or 8 years, in case they were applied in the unfermented state. But when fermented by means of urine or guano-water, as was the old practice, they became a quick-acting and powerful manure.

In point of fact, a great variety of organic matters which, in their original condition, are unsuitable for feeding plants, are essentially changed by the action of the microscopic organisms that cause fermentation, and are converted in some part into real plant-food. The idea is, that micro-organisms develop readily and rapidly in urine, or dung, or other easily putrescible substances which can supply them with agreeable food, and that when rags, or the like, are brought into contact with the ferment, they, also, become involved in the destructive processes. The rags, as well as the urine, are consumed in some part by the ferment microbes, and the unconsumed portions break up into new chemical compounds, unlike those of the original crude materials. In this sense would now be explained the old and fruitful conception that matter in a state of change, on being put in contact with other matter which is inert and at rest, may cause it to undergo changes in its turn.

Peat, also, like the organized substances just mentioned, is often, not to say usually, very much improved by fermentation. As has been said, some kinds of peat (such as may occur in limestone countries) serve very well as manure when applied to the soil directly, without weathering, fermentation, or preparation of any kind. Some sorts, moreover, ferment of themselves when thrown up into heaps, and exposed to warm, moist weather. But there are other kinds which are wellnigh useless as manures, unless they have either been rotted or fermented by means of appropriate additions, so that their gumminess, stickiness, and sourness may be destroyed; they are thus made fit for nitrification, and become capable of supplying food to plants. Excepting limestone countries, the inert peats are much more common than those which are already mellow.

In view of these differences, it is not strange that some farmers should have deemed mere exposure of peat to the air to be a sufficient preparation of this material, for the practice may be judicious as regards some kinds of peat. It is often justified, withal, by considerations of labor and the cost of distribution. But the surest and safest way of obtaining good results with peat is to ferment it artificially in the compost-heap. With peat, as with the vegetable matters, the usual fermenting agent is the dung of animals. Horse-dung is esteemed to be the best kind, though urine would be better; and fish has been used largely for the purpose, especially on the southern coast of New England. Guano has been used also as the ferment, in the proportion of one part of guano to 5 or 6 parts of peat. So, also, have blood and the offal of slaughter-houses, fish-scrap, cotton-seed-meal, soap-boilers' scraps, curriers' scraps, night-soil, and other easily decomposable animal or vegetable matters.

In case flesh is used, as when an animal has died from disease, it will be well to divide the flesh, and to distribute it in such manner that a tolerably equable mixture of it and the peat may be had. A small piece of flesh will ferment many times its own bulk of peat, provided it be brought into tolerably intimate contact with the peat. On account of the peculiarly offensive odor of such compost, it is best not to open the heaps except in winter weather. Such compost had better be hauled to the fields in cold weather, and ploughed under as soon as may be practicable in all cases. A similar remark will apply to composts made with night-soil. If care be taken to work upon such heaps in winter, the laborers will be less perturbed. There is one trouble with flesh-made composts, in that all the dogs in the countryside are apt to dig at the heaps.

Rough and Ready Methods of making Composts.

One valuable resource for making compost is the kitchen sink. Suppose that, at a convenient distance from the house, a hole be dug, three or four feet deep, and of such shape that carts can be driven into it, and that a gutter be carried to this hole from the sink. By throwing into this hole, occasionally, a quantity of peat or of sods or weeds, together with sweepings from the house, the dooryard, and the barn, and letting the liquid refuse from the house run down upon these materials, a very efficient factory of manure may be created. It will be well to shade and conceal the place with a hedge of evergreens, and to have a heap of earth handy to throw in to stop smells. This method of procedure appears to have been inherited from the Romans. At all events, several Latin writers recommended that dung-heaps should be treated in this way.

A still more simple method of making compost was described by Jared Eliot in 1747. He had a long, narrow cowyard at the roadside, into which the animals were driven every night. Once a month he took down the end fences of this yard and ran a plough through it, taking care to turn furrows up to the very edges of the yard, or as near to the side fences as was possible. The end fences were then reset, and the cows kept in the ploughed yard at night, as before, during another month, and so on through the entire summer, ploughing once a month. He finally carted the ploughed earth upon the adjacent fields, remarking that, as it was very heavy, a long land carriage was not easy. He found, as he says, "that the whole furrow depth of earth was become dung, making an increase beyond what one would imagine." "I had fourfold more," he says, "than I should have produced in the common way." The dung was spread both upon grass- and corn-land. "I did not find but that its effects were equal to those of dung." Perhaps this plan for making compost was suggested by a method of fertilizing land by penning cows upon it, which is practised habitually in several of the Southern States of this country, as will be explained in another chapter.

One item of evidence serving to illustrate the merit of composting is seen in the fact that, in some regions where the practice is habitual, the material operated upon is a particularly poor, thin, cold, sour moor-earth, which of itself is quite incapable of supporting any useful plants. Thus, on the Faroe and Shetland Islands, and in some of the least fertile districts of France, it is the custom of the peasants to strip the commons and waste-places of the thin covering of earth and "sod," and to compost this material with dung. Sometimes the earth is made to serve for bedding animals, and at others it is put where it can be crushed and trampled upon before it is made into heaps, together with layers of dung, to undergo fermentation.

"Mussel-Bed."

An instance of what might well be called natural compost is seen in the mud taken from beds of mussels in bays and tidal rivers on the coasts of Maine, New Brunswick, and Prince Edward Island, and largely used there in many localities for top-dressing grass-land, and in general as a substitute for farmyard-manure. These mussel-beds are sometimes 10 or 20, or even 30 feet thick, and the mud contains large quantities of the shells of dead mussels, as well as worms and other marine organisms, beside the thick layer of living mussels, whelks, etc., at the surface of the bed. Sometimes the mud is dug up in the autumn at low tide and thrown into scows, or it is lifted in the winter through the ice by means of dredging-machines worked by horse-power. It is so charged with animal matter from the living shell-fish, and with the carbonate of lime of their shells, that it must soon ferment much in the same way that a mixture of peat and fish-scrap would. It is usually applied to the land in the spring after having lain in heaps during the winter. Large crops of hay and of other produce are grown by means of it, and the fertilizing effect is felt for many years. Mussels are said to be largely used in Holland, also, in some parts of which country they are obtained cheaply and in great abundance. They have been specially commended there for land that has long been cultivated, and as an addition to phosphatic and potassic fertilizers.

Alkali Composts.

Beside the easily putrescible organic matters, there are other agents capable of producing fermentation in heaps of peat or of similar materials. As practical men well know, the caustic alkalies, potash, soda, lime, and ammonia, possess this power in high degree, and so do the alkaline carbonates, such as saleratus and soda ash. It was a capital observation of Angus Smith, that putrefactive fermentation will shortly set in when a soil rich in organic matter is mixed with enough alkali to saturate it, and is then left moist in a warm place. It is well known, for that matter, that the fresh urine of cows and horses has a distinctly alkaline reaction. Conversely, it is known that acids and acid salts hinder putrefaction. Pettenkofer noticed that the ammoniacal fermentation of dung and urine may be checked if means are taken to prevent the materials from becoming alkaline. Among the organisms which cause fermentation or decay, only the moulds seem to be capable of really thriving upon substances that are noticeably acid. Many kinds of fermentations are brought to a standstill by the accumulation of acid products which result from the fermentation itself. In the preparation of lactic and butyric acids from sugar, by means of ferments, it is customary to mix carbonate of lime with the sugar in order that the acids may be neutralized as fast as they form, and the process of fermentation be made continuous.

Pagel, in his turn, found that moor-earth which had been moistened with potash lye actively absorbs oxygen gas from the air, and that the absorption is more rapid in proportion as the surface of peat exposed is larger, as when, for example, inert matters are mixed with the peat. For that matter, it is now well known that the micro-organisms which cause putrefaction prosper particularly in solutions which are slightly alkaline. It is to be noted that, strictly speaking, it is the alkaline carbonates and not the caustic alkalies which are favorable for the growth of the micro-organisms which cause decay. Many kinds of bacteria are quickly destroyed even by highly dilute solutions of caustic potash or caustic soda, while they can support appreciable quantities of the carbonates of potash or soda. Of course, in actual farm practice, any soluble caustic alkali put upon peat or the like would soon be changed to a much weaker humate or carbonate of the alkali.

Manifestly, these observations go far to explain the mode of action of alkalies in compost-heaps. Lime in particular has long been an approved ingredient of composts. They serve to explain also the use by practical men of wood-ashes, of peat-ashes, gas-lime, the ammoniacal liquor of gas-works, and mixtures of lime and salt. Indeed, the observation of Smith goes to show that not only putrescible organic matter, but the gaseous ammonia evolved from it is capable of exciting putrescence in the peat or loam to which it gains access. It is probable that, while American potashes are to be bought so cheaply as has recently been the case, a valuable manure for application to leachy hungry soils might readily be prepared by drenching heaps of peat, layer by layer, with weak lye in the spring, and leaving the mixture to ferment during as many of the summer months as practice might indicate.

Compost of Lime and Sods, etc.

One method, formerly common, of preparing compost, was to dig sods from beside a wall, or to plough up an old headland, or to clear out a ditch, and to throw the material thus obtained into a heap, layer by layer, with lime, or wood-ashes, or manure, and to leave the heap for several months to ferment. After having been forked over to make it fine and mellow, such compost was esteemed to be an excellent top-dressing for mowing-fields, and especially for clover. It was applied for wheat also, and for root-crops. Lime composts prepared in this way have been found to be particularly useful on light, gravelly soils, and it has been held by some English farmers that there is no more profitable way than this of applying lime to light land.

Some of the empirical rules for the use of alkalies with peat are as follows.[1] For every cord, or say 100 bushels, of peat, take of wood-ashes, 12 bushels; of leached ashes, 20 bushels; of peat-ashes, 20 or 30 bushels; of gas-lime or spent soap-boiler's lime, 20 bushels; and of quicklime, 10 bushels, to be slaked with water just before use, or, better, to be slaked with a solution of common salt in water, or, better still, in all probability, with a solution of muriate of potash instead of the sodium salt. The peat and other ingredients are mixed as thoroughly as may be, by spreading them in layers, and the whole is built up into a compact heap three or four feet high. In case the peat is not already moist, the finished heap should be drenched with water, and then be covered with a few inches of loose peat, and left to itself. After two or three months, it is held to be good practice to shovel the heap over so as thoroughly to mix the ingredients, after which it may be covered with a loose layer of fresh peat, and left to itself until the whole of the original peat is thoroughly decomposed. Five or six months of summer weather are sufficient for the whole operation. Instead of shovelling, the heap may be ploughed over, or turned with a road scraper.

A compost of loam, wool-waste, wood-ashes, lime and potash salts, analyzed by Petermann, contained 10 % water, 45 % organic matter, 1 % nitrogen, 5 % potash, and 0.55 % phosphoric acid. More than half the nitrogen (0.66 %) was in the form of ammonia. Another compost, made from the old bags in which beet pulp is pressed, refuse straw, loam and lime, all watered with dung-liquor, contained 16.5 % water, 23.3 % organic matter, 1.88 % nitrogen, 1.77 % potash, and 0.19 % phosphoric acid.

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[1] S. W. Johnson's "Peat and its Uses," p. 72.

Alkalies corrode Organic Matters.

Apparently one exciting cause of the fermentations in alkali composts is the rapid disorganization of the vegetable matter by the alkali. That is to say, the lime, or other strong alkali, acts chemically in the first instance upon the vegetable matter, and unites with some portion of it; but the remainder is thus left in a disorganized condition, and so made subject to the ordinary processes of decay and putrefaction which are due to the presence of micro-organisms, and, as has been said, these processes are known to prosper particularly in materials which are slightly alkaline. A familiar example of the chemical action here cited is seen in some of the processes used for preparing paper-pulp from straw and from wood. By the action of hot caustic alkalies (soda and lime), certain constituents (vasculose, xylan) of the straw or wood are dissolved out from the woody fibre proper, which is the product sought for, and form dark-colored liquors from which humus-like substances may be obtained on neutralizing the excess of alkali with an acid. It is supposed, indeed, that the dark-colored liquors which drain out from dung-heaps contain similar matters which have been dissolved from straw by the action of the alkaline carbonates which are contained in urine.

Carbonate of Lime Composts.

The use of carbonate of lime as an ingredient of composts has often been commended. In some parts of the country the carbonate is employed in the form of shell-marl, but in New England it is used in the form of leached ashes. Some kinds of peat-ashes which are used for composting in Europe contain it, and so, of course, do fresh wood-ashes as a secondary ingredient, so to say. The utility of the lime-carbonate is doubtless connected with the fact that it dissolves somewhat in carbonic-acid water, and that the solution thus formed is alkaline, and consequently helpful for most kinds of fermentations; for, as has been shown on a previous page, organic matters which have become slightly alkaline are fit feeding grounds for the micro-organisms which cause decay. In this way, the lime carbonate may act indirectly to disintegrate and decompose organic matters, i. e. by fostering the growth of the ferment organisms; though as regards crude peat and other rough inert materials it can hardly be expected to serve so good a purpose as such active chemical agents as quicklime, wood-ashes, or potashes. The carbonate may be excellent, however, for neutralizing the natural sourness of peat, and after the process of putrefactive decay has run its course, it is known to promote nitrification in that it favors the growth of the nitrifying ferments. The merit of the lime carbonate is to be seen in many regions of limestone rocks and waters where the humus in the soil is conspicuously rich and mellow, and not cold and sour as is often the case in granitic countries.

In certain cases, carbonate of lime might be a useful addition to a well-weathered peat of good quality which is already so far cured as to be nearly or quite ready for nitrification, and, in the same sense, it might sometimes serve as a useful adjunct to dung composts and to those made with fish, flesh or oil-cake; though in view of the facts that much ammonia is formed during the fermentation of organic matters and that this ammonia might be expelled if lime or carbonate of lime were added too soon to the compost-heap, Pichard has urged that it might be well to mix a quantity of gypsum with the lime-carbonate in order to hinder the ammonia from escaping into the air and to hold it as sulphate of ammonia, which would be converted to a nitrate subsequently by ferment action.

Speaking in very general terms, it would appear that carbonate of lime must be inferior to the stronger alkalies in cases where it is used by itself in a compost, as the sole agent for exciting fermentation, though in dealing with a crude peat that contained sulphate of iron the lime carbonate might be the cheapest and best agent for decomposing the ferrous salt. So, too, when the object is merely to correct the sour, antiseptic quality of crude peat, carbonate of lime will serve an excellent purpose, although it may not act so quickly or so effectively as slaked lime. In time, however, either of these agents would neutralize the free humic acids and sulphuric acid, if it were present, and ferrous sulphate also.

In any event, it is important not to underrate the significance of carbonate of lime for compost-making. Schulze noticed long ago that moist peat, left to undergo fermentation after it had been mixed with powdered chalk, gave off much more carbonic acid than similar peat to which no lime had been added, showing, of course, that decomposition was rapid; and Knop expressly states that, when moist, the humates of lime and of baryta, as well as those of potash, soda, and ammonia, oxidize much more rapidly in the air than humus does by itself.

Humus ferments when Alkaline.

Petersen has determined by methodical experiments the amounts of carbonic acid that were given off from sour humus, and from that which had been neutralized by the addition of marl, when a current of air, free from carbonic acid, was made to flow slowly over the materials. His results are as follows: —

1. One litre of a heavy, sterile clayey soil of slightly acid reaction, which contained 2 % of humus, gave off by itself in the course of 16 days, at a temperature of 55° F., no more than 0.92 grm. of carbonic acid, while a litre of the same earth that had been mixed with ½ % of carbonate of lime in the form of marl gave off 2.62 grm. of carbonic acid.

2. A litre of leaf-mould containing 58 % of humus that had a strongly acid reaction gave off in 16 days' time, at 54° F., 0.89 grm. of carbonic acid both by itself and after 0.5 % of the carbonate of lime had been added to it; but in this case the quantity of marl used was insufficient to neutralize the acidity of the leaf-mould. In another trial, however, where the acidity of the leaf-mould was neutralized by mixing with it 3 % of the lime carbonate, 5.35 grm. of carbonic acid were given off in 16 days' time.

All these results are readily explicable by what is now known of nitrification. Neutralization of the sour humus promoted the activity of the nitrifying ferments, and the quantities of carbonic acid evolved in the several instances were probably pretty accurate measures of the amounts of nitrification which occurred in the different samples of earth. As has been already insisted, a trace of alkalinity in the soil, air, moisture, warmth, and ammonium compounds, constitute favorable conditions for nitrification. It is possible, moreover, that in some of these instances other kinds of fermentation, such as those which produce ammonia, may have occurred. It is not unlikely, indeed, that they have preceded the nitric fermentation. It is not to be expected, however, that so feeble a chemical agent as carbonate of lime is can act upon crude peat and other rough materials with the vigor of a true caustic alkali; though the carbonate is useful nevertheless, and may perhaps always do some good when present in a compost-heap.

Old mortar or plastering and soap-boilers' lime cannot be classed too strictly as carbonate of lime, since they are apt to contain a small proportion of caustic lime. Either of them would serve a useful purpose for neutralizing the humic acids in crude peat, and would subsequently help nitrification. Even spent gas-lime, in spite of its containing poisonous sulphides, sulphocyanides, and tarry matters, may perhaps be well fitted for correcting the sourness of crude peat, as a preliminary to composting the peat with dung. For this purpose, however, it should not be used in excess.

The following experiments were made by S. W. Johnson at New Haven, to test the effect of alkalies in developing the fertilizing power of peat. Pairs of pots were filled, —

1. With peat alone (270 grm. in each pot).
2. Peat and 10 grm. ashes of young grass.
3. Peat and ashes (as before), and 10 grm. carbonate of lime.
4. Peat and ashes, and 10 grm. slaked lime.
5. Peat, ashes, and lime, and salt for slaking.
6. Peat and ashes, and 3 grm. Peruvian guano.

Five kernels of pop-corn were planted in each pot, the pots were watered with pure water, and the plants were allowed to grow until those best developed ceased to feed upon the soil, but upon their own lower portions, as shown by the withering of the lower leaves.

The air-dried crops were as follows: —

	Weight of Crop in Grams.	Comparative Weight of Crop.	Ratio of Weight of Crop to Weight of Seed.
1. Peat alone	4.20	1	2¼
2. Peat and ashes	32.44	8	20¼
3. Peat, ashes, and carbonate of lime	38.44	9	25½
4. Peat, ashes, and slaked lime . .	43.22	10	28½
5. Peat, ashes, lime and salt . . .	46.42	11	30½
6. Peat, ashes, and guano	53.78	13	35¼

The object of the guano was to have a standard of normal action.

The peat alone was in this particular instance incompetent to supply all the food which was required; the peat and ashes did better, while by the action of the alkaline materials the inert nitrogen of the peat was made really active, and the crops grew tolerably well. The differences between the three alkalies are well marked, though of course the ashes alone were somewhat alkaline. Mention has already been made of Boussingault's observation, that the addition of caustic lime to loam largely increases the amount of ammonia contained in it, through decomposition of inert nitrogen compounds in the humus.

Compost with Lime and Salt.

The use of a mixture of salt and lime, instead of mere lime, for composting peat, has often been highly commended. The idea is a very old one. More than two hundred years ago, the chemist Glauber told how to mix the salt with the lime, and insisted that the mixture is most fit for dunging the land. Sir Humphry Davy, in his work on Agricultural Chemistry, mentions the fact that several practical men have derived more benefit from the use of lime moistened with sea-water than from common lime. The late Dr. Dana, of Lowell, brought forward much evidence in favor of the mixture, in his "Muck Manual"; and it has been used in the Cotton States with so much advantage, that there was talk at one time of removing a duty on salt as a means of encouraging the growth of cotton. The advantage gained by using a mixture of salt and lime, rather than lime alone, or carbonate of lime alone, depends upon the facts that "bi-carbonate of lime" is capable of reacting chemically upon common salt (or on any other alkali chloride, and on alkali sulphates also), with formation of "bi-carbonate of soda," and that the sodic carbonate thus formed can promote the decomposition of peat more effectively than could be done by the weaker and the less soluble alkali lime.

To state the matter in somewhat more general terms, it is true that common salt and carbonate of lime, when in presence of carbonic acid and water, can react upon one another with formation of "bicarbonate of soda" and chloride of calcium. Practically, under the conditions which obtain in a compost-heap, it is to be presumed that the super-carbonate of soda thus formed will be a sesqui-carbonate rather than a bicarbonate. In many cases indeed, the product may contain less carbonic acid than a sesqui-carbonate; it may even happen that it will hold in combination but little more carbonic acid than the amount proper to normal carbonate of soda. In the words of Hilgard and Weber, "We must, as a rule, expect to find mixtures of the alkali mono- and sesqui-carbonates in varying proportions, according to condition of temperature, supply of carbonic-acid gas, and other conditions."

In making a compost with salt and lime, the usual method of procedure is to slake quicklime with brine and to spread the powdery product, layer by layer, upon moist peat that has just been thrown out from the bog. Under these conditions, a good part of the lime will speedily be changed to the condition of a carbonate, and some of it to the state of super-carbonate, for there cannot be any lack of carbonic acid in the heap, inasmuch as this substance is formed there incessantly through the decomposition and oxidation of the peat. Hence the conditions are all favorable for the above-mentioned reaction between the lime-carbonate and the salt; and the soda-carbonate thus formed will naturally diffuse into the moisture of the heap and so be brought into contact with the peat in all directions.

The fact of the formation of crusts of carbonate of soda upon the surface of the soil in many desert places where salt and limestone are in contact with one another, has frequently been observed since a very early period, but the true explanation of the method of their formation has only recently been recognized, first by Hilgard in California.

There can be no doubt that the use of the salt and lime mixture is preferable to the use of lime alone, as a general rule. But now that a clew to the mode of action of the mixture has been discovered, there is room for very grave doubts whether the use of the salt and lime should be continued, for it can hardly be doubted that carbonate of soda could be applied to peat more methodically and economically in the form of black-ash, soda-ash, or, better yet, in that of barilla from Teneriffe. Practical men have often called attention to good results obtained by them on composting peat with soda-ash, and there can be no question that soda-ash may be an extremely valuable fertilizer in many localities, especially in non-calcareous regions where the soils are apt to be or to become sour.

Potash better than Soda.

Soda-ash has the merit of cheapness. Excepting places where wood-ashes are abundant, the alkaline soda-carbonate can usually be obtained much more cheaply than the corresponding compound of potash. But while potashes are so cheap as they are now, and are likely to continue, it may well be asked whether they should not be used in most instances for compost-making rather than soda-ash. Potash is a manure in itself, a necessary form of plant-food. Soda has no such claim upon the farmer's attention. Plants can succeed perfectly well without soda, and as an alkali it has no advantage, other than cheapness, over potash. Practically the chief lesson to be drawn from the "salt and lime mixture" is, that the time-honored method of composting peat with wood-ashes is a good method, and that it should be inculcated and improved upon. In case local circumstances should favor the use of lime, some one of the cheap potash compounds from Stassfurt might well be mixed with it instead of common salt. H. Liebig has proposed the following receipt: For every 100 lb. of peat, regarded as air-dried, take 200 lb. of quicklime and slake it with a solution of 200 lb. kainit. To this compost Liebig would add 100 to 200 lb. of bone-meal, or superphosphate or precipitated phosphate of lime.

Action of Lime on Dung.

In connection with the subject of the action of alkalies on peat, some mention should be made of their action upon fresh dung, or on dung that is fermenting in moist heaps, although not much is known accurately concerning these matters.

From dung which is undergoing hot fermentation, caustic lime or any other of the fixed alkalies will of course expel large quantities of ammonia; but there is some evidence which goes to show that lime does good rather than harm when spread upon the surface of ordinary moist dung-heaps, and Payen has urged that the addition of small quantities of lime to fresh dung or urine retards their decomposition considerably instead of hastening it. There seems to be an actual union between the lime and some of the nitrogenized substances when they are in the fresh condition, as has been explained in another chapter.

The following experiment, by Wolff, is of interest. He mixed 250 grams of quicklime, that had been allowed to slake in the air, with fresh cow-manure in a box of one cubic foot capacity, and left the mixture to decay in a north room during 15 months. It weighed some 11,000 grams at first. The loss of water from this mixture was rather more rapid, and was larger in amount, than occurred with similar boxes of mere manure, and of manure and gypsum, which were tested at the same time. But it appeared that, as was the case with the gypsum also, the final product contained a smaller proportion of soluble organic matters than dung which had rotted by itself; whence the conclusion that the lime must have combined with certain organic matters to make them insoluble. It is probable, withal, that some of the matters thus fixed by the lime would have decomposed very readily if left to themselves. The limed manure contained, when rotted, more organic matter, and more nitrogen also, than the simple rotted manure; and there was a larger proportion of nitrogen in the organic matters of the limed manure, both in those that were soluble and those which were insoluble in water.

Composts of Lime and Dung.

In some parts of Western France, where the soils have been derived from granites and slates that contained but little lime, it has long been customary to use both lime and dung in the preparation of composts. It is said that a quantity of quicklime is thrown into a rectangular hole, which has been dug in a field, and there covered with loam. The lime soon slakes and falls to fine powder, which is shovelled over and intimately mixed with the loam. Manure is then hauled to the side of the hole, and the mixture of lime and loam is thrown out upon the manure, so that a heap is built up of alternate layers of the two materials. After the heap has lain for two months or more, the compost is applied to the land. It is evident that this process may have merit in regions where the soils are apt to be sour, but in most countries farmers seem to have preferred to use carbonate of lime rather than quicklime in making composts by means of dung.

Composting Refuse.

Almost everything that has been said of composting peat, either with dung or with an alkali, will apply to a multitude of other materials beside peat. As regards straw and leaves, indeed, and other easily decomposable vegetable substances, the theory and practice of fermentation seem to be tolerably well understood. But there are many things, such as the stalks of corn, of potatoes, of buckwheat, and of beans, twigs clipped from hedges, bushes mown in pastures, chips and sawdust, clods and weeds, which can perfectly well be decomposed in the compost-heap by proper treatment, and which could probably be decomposed there economically instead of being burned to ashes, as is now done far too frequently.

It may sometimes be well, no doubt, to burn trash for the mere sake of getting rid of it, and the use of fire often seems to be justified also as a means of destroying fungi, the eggs of insects, and the seeds of weeds; but in all probability the destruction of these pests could readily be effected by means of weak solutions of potashes, and the nitrogen of the organic matters that harbored them be saved at the same time for the farm. Rubbish thus drenched with potashes would naturally decay quickly in warm weather if it were kept in a damp place. For example, it might perhaps be found advantageous to compost in this way the refuse leaves and vines which are left when hops are harvested, instead of burning them to ashes, as was the old English practice. It is to be noted that, on farms where no advantage is derived from potassic fertilizers, soda-ash would be a cheaper and an equally effective agent for decomposing weeds or the like.

Slaked lime, admixed with green weeds in the proportion of 10 or 15 % of quicklime to 85 or 90 % of weeds, is said to decompose them so speedily that the mixture is fit for use next spring, though the lime would not be nearly so apt as potashes to destroy all the seeds. In general, soluble alkalies, like potash and soda, or their carbonates, must act much more effectively to destroy weed-seeds than any method of merely composting with dung, although it is true enough that some seeds are destroyed in heaps of dung-compost.

It has been recommended in Europe, in cases where the fodder or the litter contains many weeds, to compost the manure with loam, and to drench the heaps frequently with dung-liquor in order to rot the weed-seeds. The practice is akin to a plan for killing cotton-seeds formerly in use at the South, though it can hardly be as effective as that was, because many weeds bear seeds which are peculiarly hard and refractory, and wellnigh impermeable to moisture. Indeed, it has been noticed recently that the seeds of various weeds do not perish in silos of corn-fodder, even when much heat has been developed by the fermentation. It would appear that only those seeds are destroyed in a silo which are soft enough to swell under the conditions which obtain there. The mere heat of the place is not high enough to destroy many of them. "I am certain, by demonstration," said Tull, "that, let a dunghill remain three years unmoved, though its bulk be vastly diminished in that time and its best quality lost, charlock seed will remain sound in it, and stock the land whereon it is laid; for that ferment which is sufficient to consume the virtue of the stercoraceous salts is not sufficient to destroy the vegetative virtue of charlock seeds, nor, as I believe, of many other sorts of weeds." Lorain, in his turn, urged that, "Although the cookers of dung say that the fermentation of it destroys the vegetative property of seeds, practice and observation determine the contrary. In fact, if nature had not calculated seeds in general to withstand much more than the heat of a fermenting dunghill, the earth would long since have been stripped of vegetation, particularly where ploughers and croppers reside."

It is not improbable, however, that many weed-seeds may be killed by exposure to the long-continued putrefactive processes to which manure is subjected in the deep, wet dung-pits of Continental Europe; though this view is weakened by certain experiments of Zoebl, who observed that some seeds — notably those of bind-weed (Polygonum convolvulus) and black medick (Medicago lupulina) — retained their germinative power after having lain 50 or 60 days under dung-liquor.

Value of Coarse Refuse.

The chief points to be considered in composting coarse materials are, that more time must be allowed for their decomposition than for the decomposition of finely divided substances, and that special care must be taken to make the heaps of coarse materials large, and to keep them moist. It is evident that, in order to get the best results, the coarse materials should be fermented by themselves in special heaps. There would be a waste of time, and risk of losing fertilizing matters, if fine materials were left to rot with coarse during the long time necessary for the decomposition of the latter.

A general idea of the value of some common kinds of refuse may be got from the following table, which gives in round numbers the percentage proportion of water, nitrogen and ash ordinarily contained in them: —

	Water.	Nitrogen.	Ash.
Straw of wheat	5 to 10	0.5	4 or 5
" " rye	8 to 10	0.2 to 0.4	4 or 5
" " barley	8 to 10	0.3 to 0.5	5 to 7
" " oats	8 to 10	0.6 to 0.7	5
" " buckwheat	10	0.5 to 0.7	5 or 6
" " peas	10 to 12	1 to 2	4 to 6
" " horse-beans	12 to 14	2.	5 or 6
Potato vines	10 or 12	1.5	10 or 12
Beet leaves	87 to 90	0.5	13 or 14
Carrot leaves	70	0.5 to 0.9	8 or 10
Autumn leaves of trees	10 or 12	0.7 or 0.8	4 to 6
Summer leaves of trees	55	0.9	2 or 3
Sawdust, oak	25	0.5	1 or 2
" spruce	25	0.25	0.5

Marc of grapes	48	1.8	4 to 6
Chaff of wheat	8 to 10	0.8	9 or 10
" " barley	10 or 12	0.5	10 or 12
Clover-roots	9 or 10	1.6	9
Purslane (Portulaca)	93	0.4	2
Pig-weed (Chenopodium)	81	0.6	4
Nettle (Urtica)	82	0.9	2 or 3
Yellow dock (Rumex), dry leaves	12	3.5	11
Milk-weed (Asclepias) " "	15	3.8	9

Looking at the matter from the two points of view which have been insisted upon, — viz. 1st, the preservation of dung, and, 2d, the decomposition of inert vegetable matter, — it would seem as if in general, at least for all farms where neat cattle are kept, that the coarser sticks and stalks and clods should be treated with a special view to their fermentation, and that the finer straw and leaves, as well as peat and loam and clay, should be made to serve in the first place as bedding for cattle, or as absorbents of their liquid dejections. The finely divided materials will usually be sufficiently decomposed when thus treated, without need of special oversight. But if all the coarse materials were banished to special heaps, there would seem to be less need of that incessant forking over of dung- and compost-heaps upon which so much labor was formerly expended, and still is, indeed, on many farms. The cost of merely moving manure from the stable to the field, which commonly involves the carting of it twice and the handling of it four or five times, would seem to be sufficiently expensive, under the most favorable circumstances, without expending in repetitions of the turning process any labor that can possibly be avoided. It must be admitted, however, that there is still much to be learned as to the reasons why the practice of forking over manure persists. Doubtless, there are other points gained by the process beside the mere decomposition of the long litter. Although there is some diversity of opinion with regard to the advantage of turning over compost-heaps, the general impression among farmers seems to be that the oftener the heaps are worked over during or after fermentation, the better.

Spent Hops.

Spent hops, as thrown out from breweries, have often been commended by practical men as excellent for composting and for putting into hog-pens; and there can be no doubt that the material is well suited for these purposes, in view of the large amounts of organic matter and of nitrogen which it contains. It is said that in some localities spent hops are highly esteemed by market gardeners, who describe the well-rotted material as a valuable fertilizer, free from weeds and so fine that it mixed easily with the soil when harrowed.

Hop-waste ferments readily when it is moist, though it dries rapidly when spread out and exposed to the air. When thus dried, it serves excellently for bedding cows, since it absorbs much urine and is then fit to be used immediately as manure. Indeed it has been said by some that the best effects are obtained when hop-waste that has served as litter is applied to the land in the fresh, unrotted condition. As thrown out at the breweries, heaps of wet hop-waste are apt to become very hot through fermentation, and to give off an unpleasant odor. In a sample of hop-waste examined by Church there were 57 % of water, 40 % of organic matter, 1.3 % of ashes, 1.91 % of nitrogen, and 0.8 % of phosphoric acid. A sample of air-dried hop-waste examined by Spiers contained 10 % of water, 3.31 % of nitrogen, 5.34 % of ashes and sand, and 3.52 % of ashes. The crude ashes contained 11.27 % of potash, 26.1 % of phosphoric acid, 14.7 % of lime, and 12.1 % of magnesia.

Some practical men have urged that by mixing spent hops, while they are fresh, with brewers' grains, they may be made to serve a good purpose for fattening neat cattle. Animals are chosen which have never become accustomed to eat mere brewers' grains, and they are gradually accustomed to eat the mixture of grains and hops. After a while they become fond of the mixture and thrive upon it. Analyses of spent hops seemed to show that they resemble, as to their composition, clover hay of medium quality; but Kellner, and Weiske, have found, on trial, that sheep can digest only a comparatively small proportion of the albuminoid constituents and the carbohydrates in spent hops. Far from being comparable with good clover hay, this material is really no better fodder than the straw of legumes or than meadow hay of rather low grade. Spent hops have undoubtedly a certain small value as a food fit for maintaining neat cattle or sheep, but it stands to reason that on mixing them with brewers' grains, as above, or with other kinds of cattle food, no very large proportion of the hops should be used.

Ripe Compost.

It is noteworthy that, in regions where the winters are not too severe, compost-heaps are sometimes covered over at the beginning of winter with straw, sods, brush, potato-tops, or the like, and occasionally even with horse-manure, in order to exclude frost. In this way the heap is kept unfrozen, so that its contents can be forked over at any time, and removed to the fields at the farmer's convenience. Perhaps such protection might be applied usefully with us both to compost-heaps and heaps of peat that are to be used in midwinter for compost making. It deserves to be studied whether the old plan of planting squashes, pumpkins, melons, or other free-growing plants, upon compost-heaps has any other merit than that of yielding a small crop at trifling cost, and of hiding the heaps from view. The shade and surface moisture afforded by the plants may perhaps promote nitrification; but, on the other hand, the plants must necessarily pump up great quantities of water, and tend to dry out the interior of the heap.

A good deal of importance is attached by some writers to the idea that compost should be "ripe" when applied to the land; and it is taught that the time needed to ripen a compost-heap may vary all the way from a few months to two years, according to the materials and to the season. Indeed it has been said of the rich compost of loam and manure called "terreau," which is used by market gardeners at Paris, that it cannot be properly made in less than four years. The Parisian gardeners, instead of planting vegetables in the natural soil, prefer to grow them in beds of terreau placed upon beds of long manure in such manner that the gardens are practically great hot-beds, covered more or less with glass during the colder months, but open to sun and air in the spring and summer.

Care should be taken always to establish compost-heaps early enough, that they may be ready for use at times when fields are to be planted. Perhaps the best plan of all is to have a number of heaps in all stages of progress toward ripeness. The idea of ripeness means of course that much of the nitrogen in the peat or other rough material has been brought to a condition favorable for rapid nitrification when the compost is put upon a field. Possibly some of the good nitrogen in a ripe compost may be already in the form of an ammonium compound; but it is more probable perhaps that much of the nitrogen may have been reduced to the condition of amids of such character that they can change readily to ammonia and to nitrates in the field.

The chief advantage gained by stirring compost seems to be, that, up to a certain point, fermentation sets in anew each time the heap is turned over in such manner that its contents are loosened and exposed to the air.

This idea was presented somewhat forcibly by Cobbett, long ago, in the following words: "A great deal more is done by the fermentation of manures than people generally imagine. In the month of June take 20 cart-loads of earth which has been shovelled off the surface of a grassy lane, or by a roadside, or round about barns, stables, or the like. Lay these 20 loads about a foot thick on some convenient spot. Go and cut up 20 cart-loads of [green] weeds of any sort, and lay these well shaken up on the earth. Then cover the weeds with 20 more cart-loads of earth, like the former, throwing the earth on lightly. In three days you will see the heap smoke as if on fire. If you put your hand into the earth you will find the heat too hot to be endured. In a few days the heat will decline and the heap will sink. Let it remain for a week after this, and then turn it carefully. This will mix the whole well together. You will find the weeds and the grass in a putrid state. Another heating will take place, but less furious than the former. Turn it a second time in 7 days, and a third time in 7 days more. By this time you will have 40 loads of manure, equal in strength to 20 loads of yard-dung, and better for a garden, or indeed for any other land. . . . When such a heap were once formed, some ashes, fish-shells or bones reduced to powder, or other enlivening matter, might be added to it and mixed well with it."

According to Miller, it is necessary to mix earth or mud or some other diluent with green weeds to prevent the heaps from taking fire when they ferment. This accident is specially liable to occur when the heaps are large, unless the weeds have been mixed with earth, or the like. When the weeds are thoroughly rotted, such compost will cut like butter, and will greatly enrich the land. It is to be presumed, of course, that the first hot fermentation in such extreme cases as these must have been an ammoniacal fermentation.

Labor to be Spared in Compost-making.

It may be true, also, that the formation of nitrates or nitrites is promoted by the admission of air to the mass, though it is not to be supposed that nitrification could occur at any great distance from the surface, or at the interior of the heap. So far as the establishment of a new fermentation goes, the occasional turning over, at leisure moments, of those compost-heaps which contain coarse material, would seem to be judicious; but the process would seem to be open to adverse criticism as regards ordinary heaps, such, for example, as those composed of peat and dung. If the object in forking over the heap is merely to decompose the peat somewhat more thoroughly, it will be well to count the cost of the labor involved before much of that kind of force is expended for what is probably a comparatively small gain. Even if it be admitted, for the sake of the argument, that the compost is benefited decidedly by being worked over, it may still be urged that the benefit is not commensurate with the cost. It would probably be far more judicious, in most cases, to expend the labor either in hauling or in getting out new supplies of peat or of sods, and in establishing new heaps of compost, rather than in turning over the old heaps; provided always that the materials of the heap are in a tolerably finely divided condition.

For horticultural purposes, indeed, it may often be well to turn over a heap of dung or of compost many times and often, in order to provide delicate food for some cherished plant. But in agriculture the methods are coarser. An abundant supply of tolerably crude manure will usually serve the farmer a better purpose than a scanty supply of manure that has been highly refined; and he can nowadays always buy a little nitrate of soda or of an ammonium salt to enliven the manure, if need be.

Many years ago, Boussingault tested old composts obtained from several different farms and market-gardens in France, and found no inconsiderable amount of nitrates in each of them. Stated in terms of nitrate of potash, he found that the dried compost contained, in different instances, 0.083 %, 0.094 %, 0.107 %, and 0.151 %. In a compost of leaves, he found 0.551 % of saltpetre. The sample above-mentioned which contained 0.107 % was from a heap of horse-manure and loam that had lain 4 or 5 months on the premises of a market-gardener. As Boussingault remarked, these quantities of nitrates are not so very much smaller than were the amounts obtained not infrequently from the nitrous earths of the old saltpetre boilers.

Composts may be made far from Home.

One great advantage in composts is, that they can be made far from home. Suppose, for example, that there is an outlying field that needs to be fertilized. It will often be better practice to get out pond-mud, or peat, or sods, at the locality itself, and haul thither enough dung, or lime, or ashes to compost the inert materials than it would be to haul dung enough to manure the entire field. A similar remark will apply to home fields, which are not readily accessible at certain seasons.

One word should be said about the forking up of great heaps of manure in the spring, by the market-gardeners, where the chief motive seems to be the using of the heat of fermentation. When brought to the cold ground, the hot manure warms it considerably, as will be explained in a subsequent chapter, and so insures a better start to the early peas or other vegetables which are to be grown there. Horse-manure is esteemed for this purpose, and that which contains straw is held to be better than that which is mixed with bog-meadow hay. In this case, the gardeners are really seeking to get a feeble form of bottom heat, such as is seen at its best in their hotbeds. Twenty-five cords of such manure to the acre, which is a not unusual application, are clearly competent to force an early crop, both by virtue of the heat developed, and of the large amount of nitrogen which the manure contains. It is probable, withal, that nitrification speedily sets in where the land has thus been prepared and warmed, as if for this special purpose, by working into it such large quantities of manure.

Composts regarded as Saturated Earths.

There is still another way of looking at composts beside those already described, and it is the usual method of regarding them; namely, as "earths saturated with easily assimilable plant-food." There are many cases where the crop will succeed better when treated with such saturated earth than if it were dressed with clear dung. Take the case of "dunging in the hill," for example; it will manifestly be better to have a shovelful of compost left in contact with the seed than a mass of dung. For fresh dung might rot the seed, and hot manure would be likely to "burn" it, as the term is. Moreover, crops like beets and potatoes have no such powerful roots, when young, that they can afford to search for their food at great distances. They do best when a "saturated earth" is supplied to them in the beginning close at hand.

Again, for top-dressing mowing-fields and pastures, the saturated earth is specially well fitted. There are some soils withal, such as dry sands, where dung does not decompose advantageously, and it is precisely on such soils that the saturated earth does most efficient service. But, as hardly needs to be said, this saturated-earth theory is taken somewhat after the fact. It concerns itself with the uses to which the product is to be put, rather than with the scientific explanation of the mode of manufacture.

Composts are really Earths charged with Microdemes.

In the light of existing knowledge, it is more reasonable to consider composts as earths charged with microscopic organisms, such as bring soils into a good state of fermentation and help to increase fertility either by changing into new forms matters which are already contained in the soil, or possibly sometimes by working to fix free nitrogen from the air. In order to grasp this conception clearly, the student will do well to contrast ripe compost with crude and barren earth, such as may often be seen upon the sides of ditches, roads, and railways where banks have recently been cut through. Earth thus laid bare may remain sterile even for several years after the excavations are made; and the inference is, that it does not contain the organisms which promote fertility. In the absence of these organisms, no proper fermentation can occur, and the earth remains infertile. But by strewing a good compost upon such land it would not be difficult to establish vegetation upon it, especially if pains were taken that the slope should not be too steep, and if a furrow were drawn upon the land at the upper edge of the slope to lead away rain-water, and so prevent the slope from being washed and gullied.

Phosphatic Compost.

In some cases it may perhaps be well to incorporate with composts, during the process of preparation, phosphates of one kind or another, such as ground phosphatic slag, or Florida phosphate, bone-black, bone-ash, ground phosphatic guano, or possibly even one of the better kinds of ground phosphate rock ("floats," so called). The chief objection to this idea is that the process of composting does not exert any very powerful action upon such phosphates. It is true enough that insoluble phosphates are slowly attacked to a certain extent in an ordinary compost-heap, but the action is slight and feeble and not much to be depended upon as a practical resource; unless indeed, as sometimes happens, the peat employed contains free sulphuric acid. (Holdefleiss.) Whether precipitated phosphate of lime might not sometimes advantageously be scattered upon the compost at the moment of turning it, is a question to be decided by experience. This phosphate is an excellent fertilizer for many purposes, and may readily be applied by itself, but possibly enough it might serve a useful purpose in the compost-heap by feeding there the micro-organisms which cause decay, and it might afterwards do as much good to the crop as if it had been applied directly to the land. In the case of moor-land which contains free sulphuric acid, an application of phosphatic slag, after draining, could hardly fail to be useful.

It is a strong point to be urged in favor of phosphatic composts that phosphate of lime promotes putrefaction; evidently by serving as food for the micro-organisms which cause decay. It was noticed some years ago by Collas that particularly active putrefaction sets in on adding small quantities of phosphate of lime to flesh or to isinglass, and this observation has been confirmed by Lefort, who could not find any other compound so efficient as the phosphate, in this regard.

Dry Loam may injure Manure.

Thus far it has been argued that the mixing of peat, loam, or straw with dung is in the main advantageous as a means of preserving the manure, provided the mixture is kept moist and cool, even if it be exposed to the air, and in case a heap of moist manure were to be covered with impacted earth the presumption is that the manure would be preserved much in the same way as if it had been stored in a silo. Holdefleiss has found in fact that very little nitrogen is lost from heaps of well-conditioned manure that have been covered with loam. In his experiments on this point, it was exceptional when as much as 1.8 and 2 % of the original nitrogen were lost. But there is another side to this question of admixture, for practical experience goes to show that when dung or urine are mixed with an excess of dry loam or dry peat, and then exposed to the free action of the air in loose heaps, there is danger that a good part of their nitrogen will be lost. This particular point has not yet been sufficiently studied, but it would appear that the loss of nitrogen must depend upon some process of oxidation due to the free admission of air through the loose materials. It has been proved by several different observers that when nitrogenous organic substances undergo decomposition in presence of much oxygen, considerable quantities of free nitrogen gas may be evolved from the materials; and there is no lack of farm experience to teach the importance of hindering free oxygen from gaining access to the interior of manure-heaps.

Moreover, Gibson has shown, by adding an infusion of loam to flesh and to blood-serum which were decaying in presence of air, that certain micro-organisms from the loam brought about fermentations of the blood which were attended with liberation of very considerable quantities of free nitrogen gas. In these particular experiments, the liberation of nitrogen by the loam-microbe was wholly independent of any process of nitrification. But it has been observed repeatedly by many different chemists, that when nitrates are present in fermenting manure or in other kinds of decaying organic matter, they are apt to be deoxidized in such manner that some of their nitrogen goes to waste as such.

Nitrogen Lost from Nitrates during Putrefaction.

Tacke, for example, has shown that large losses of free nitrogen may occur during the putrefaction of moist organic matters with which a nitrate has been mixed. In his experiments a variety of crushed vegetable matters such as beet-root and clover leaves and various moist mixtures of flesh with meal, starch and sugar were made to putrefy, but in the absence of nitrates no appreciable amount of free nitrogen was ever exhaled from these mixtures, no matter whether the putrefaction occurred in the entire absence of oxygen gas or in presence of an excess of it. On the other hand, when a nitrate was added to the organic matters which were putrefying, this nitrate was immediately reduced, and an abundance of free nitrogen was evolved, together with varying amounts, in many cases, of the other products of reduction, viz. nitrous oxide, nitric oxide and nitrous acid. When the putrefaction occurred in an atmosphere of oxygen gas the reduction of the nitrate was less vigorous than in cases where no free oxygen was present, but in no case did it wholly cease, though perhaps this result might have been attained if it had been possible to bring the oxygen gas into intimate contact with every particle of the putrefying matter. In general, it was observed that the reduction of the nitrate was more emphatic in proportion as less free oxygen was present.

The reduction of nitrates in this way manifestly depends upon the presence in the putrefying mass of certain micro-organisms which consume the oxygen of the nitrate. It has been claimed indeed by Gayon and Dupetit that they have isolated and examined these organisms. Tacke's results have been corroborated by those of Ehrenberg, who finds that in the absence of oxygen gas, an abundance of free nitrogen escapes from putrefying organic matters with which nitrates have been admixed. When the putrefying matters are placed in an atmosphere of pure oxygen, the evolution of nitrogen will cease after a time, for in this case the ferment organisms will use the free oxygen and no longer take oxygen from the nitrates. In his trials with putrefying organic matters, both moist and wet, which were free from nitrates, Ehrenberg could not detect any evolution of free nitrogen, neither when oxygen gas was absent nor when it was present in excess. In consonance with these results, Kellner has noticed that there is an appreciable loss of free nitrogen from organic matters which are undergoing the process of nitrification.

Even before the publication of the foregoing observations, Dietzell had urged that whenever free nitrogen is lost during the decay of organic matters, this loss is in some way connected with the formation of nitrites by way of fermentation, and it is known that when nitrites are brought into contact with amines or amido-acids, such as urea or leucin, tyrosin and other products of the decay of nitrogenous matters, they are liable to be decomposed with evolution of free nitrogen gas. Dietzell claims that this loss of nitrogen during decay may be prevented by mixing the organic matter with precipitated phosphate of lime or with powdered phosphatic slag.

Oxidation by Dry Loam is due to Micro-organisms.

It is to be noted that the loss of nitrogen through reduction of nitrates and nitrites is quite a different matter from the liberation of nitrogen by the action of loam-microbes on decaying substances which contain no nitrates, as studied by Gibson; and that these loam-microbes of direct action would appear to be of paramount importance as a cause of the slow destruction of manure in loose dry heaps. It is not yet known whether the injury which manure suffers when it is left loose and dry may be complicated with processes of nitrification, though the presumption would be adverse to any such supposition because of the lack of moisture. But there can hardly be a doubt that the decompositions which are known to occur in such heaps must depend in good part on the presence of aerobic ferments which feed upon the organic matter as well as upon oxygen gas, and thus bring about the wellnigh complete oxidation of the organic matter. Dry earth, or any other material porous enough to permit the free entrance of atmospheric air, while acting at the same time to subdivide the organic matter and to increase the number of points of contact between it and the air, must favor the multiplication and the effective working of the ferment.

I have myself observed in the case of loams that were kept for months and years in an absolutely air-dried condition that the organic matter suffered slow decomposition with formation of much carbonic acid.

As has been said already, under Dung, — beside putrefaction proper, and the anaerobic fermentations, which need no air for their completion — there are processes of slow decay, or "slow combustion," as the term is, which, though due like the others to the action of microscopic organisms, are characterized by the fact that air is necessary for their progress. It is the so-called aerobic ferments which cause the decay of manure in loose heaps and the waste of humus in cultivated fields; and it commonly happens, while one kind of fermentation may be going on at the centre of a dung-heap to which no air has access, that decay of a totally different order is progressing at the surface of the heap; as deeply, that is to say, as air can find entrance to the materials. It is notorious that all substances habitually in contact with the air — such as the surfaces of plants, the skins of animals, the feathers of birds, the soil itself and everything that rests upon the soil — are apt to be highly charged with bacteria which settle out from the air, as dust settles, because they are heavier than air. This statement may readily be verified by putting minute particles of earth, or of any substance that has long been exposed to the air, upon food prepared expressly for the growth of bacteria, and observing with the microscope how rapidly the organisms develop there. In one instance studied in this way by Koch, it was noticed that while the uppermost layers of the soil contained innumerable germs, very few could be detected at a depth of two feet, and none at a depth of three feet.

It is to be remembered, none the less, that the experiments of Schloesing, already cited, have shown that some part of the oxidation which occurs in loose manure-heaps must be attributed to chemical action, pure and simple, and it is to be observed that porous substances, such, for example, as charcoal, or, better yet, spongy platinum, may exert a powerful influence upon foul odors to destroy them.

Oxidation by Porous Bodies.

The decomposing action of porous bodies is well shown by a common lecture-room experiment, which consists in covering the body of a rat or squirrel with a little heap of bone-charcoal, and leaving the heap undisturbed for some weeks. It is then found that the putrescible portions of the animal have disappeared, and that little or nothing of him is left but bones and hair. But meanwhile no odor has been perceived to arise from the heap of charcoal, excepting a very faint smell of ammonia. So long as any moisture is left in the animal, his flesh probably decomposes rapidly by the action of aerobic ferments, and in case any of the products of the decomposition are offensive, they would be absorbed and destroyed by the porous coal.

There appear to be three points worthy of special notice in respect to this so-called disinfecting action of charcoal; viz., the easy access of air to the organic matter, through the loose particles of the coal, whereby the activity of aerobic ferments is promoted; the power of the coal to absorb volatile matters; and the fact that the substances thus absorbed react chemically upon one another. The charcoal absorbs the offensive matters together with air, and thus forces the oxygen of the air into such close communion with the offensive compounds that the latter are burnt up and destroyed. In some foreign cities, sieves of charcoal have been placed across the air-vents of sewers in such manner that the outgoing air should all be filtered through the charcoal, and so be disinfected. Chemists are familiar with the fact that bone-charcoal actually does possess considerable oxidizing power, in this sense, and methods have been devised for putting it in evidence by means of lecture-room experiments. It is to be noticed that, as a general rule, the charcoal, far from exerting any preservative influence, actually hastens the decomposition of the organic matter. Its action was well exemplified in the case of some trout caught by a student in New Hampshire, and packed in charcoal powder there to "preserve" them, but which, on being sent express to his friends in Boston, were received by them in an advanced stage of decomposition.

It may be remarked in passing that the familiar practice of charring those portions of the butts of posts or poles that are to be buried in the ground, in order to preserve the wood, depends upon other considerations than the foregoing. The action of the fire destroys the outermost layer of the wood, i. e. it there destroys the nitrogenous and amylaceous matters which would naturally have served as food for the microscopic organisms which abound in damp earth. The charcoal itself cannot serve to nourish these organisms, and by covering the wood which is beneath it, it protects this wood to a considerable extent, though finally when the post is dug up after the lapse of years, the external layer of charcoal will alone be found in a sound condition. It is to be remembered also that when wood is strongly heated a variety of acid, tarry and empyreumatic substances are formed which permeate the uncharred portions of the wood, and for a time act as germicide agents to prevent decay.

Common experience teaches that dry earth acts to deodorize fetid matters, and apparently it does so somewhat in the same way as charcoal, though to a less degree. The habits of mankind with regard to the burying of dead animals, and of all offensive matters, well illustrate this point. Doubtless the earth may do good service by destroying offensive emanations from the putrefying matters, as charcoal does, but it must often happen that buried materials will simply be destroyed, which by proper treatment, might have been saved to serve as fertilizers.

Destructive Power of Porous Earth.

To repeat, the destructive power of earth is mainly a consequence of its porosity. The drier the earth, up to a certain point, so much the greater will be its destructive power, for in moist earth most of the pores are filled, and stopped up, as it were, with water. But even moist earth must exert some of this destructive power, unless it be compacted tightly; and in most manure-heaps some parts of the heap will be loose enough and dry enough to be subject to more or less of this kind of decay.

It is an admitted fact in natural philosophy, that by force of adhesion, every solid substance exposed to the atmosphere, or to any other gas, is covered with a thin film or coating of air, or of the other gas. To some substances, like metallic platinum, gases adhere with peculiar force, and so they do to many porous bodies; i. e. substances whose interstices present a large surface in proportion to their bulk. A familiar instance of such adhesion is seen in the clinging of tobacco-smoke to curtains and other woollen articles; and, as has been said, more or less carbonate of ammonia may be retained by the soil in this way, especially by clay. (See "How Crops Feed," p. 243.)

The air or other gas thus held as a film upon the solid substance must evidently be very much compressed as compared with atmospheric air, and must consequently be peculiarly ready to act or to be acted upon chemically. Moreover, air thus held attached to porous bodies may serve as a reservoir or source of supply for the support of micro-organisms, even in the midst of a great heap of inert materials.

Perhaps because the substances experimented upon vary so widely in respect to porosity, it is not easy to obtain clear conceptions as to the limitations of these facts, or as to their practical importance in respect to the preservation or destruction of heaps of ordinary compost or dung. For instance, there is an experiment by Wolff, in which 150 grams of finely powdered charcoal were packed with cow-manure in a cubic-foot box, and left in a north room for 15 months. The mixture, which weighed about 15,000 grams at first, hardly lost weight any more rapidly than the mere manure with which it was contrasted, and it contained as much nitrogen as the latter at the close of the experiment.

There are experiments by Stanford, also, in which little or no nitrogen was lost from small quantities of meat, urine, and excrement which had been admixed with charcoal, and left during the summer months in loosely covered dishes. All these results seem to point to the conclusion that the oxidizing action is hindered by extreme dryness. Apparently, a certain small proportion of moisture should be present in order that the destruction of organic matter by the micro-organisms which live in porous earth may be really rapid; though, as was just now said, I have myself observed that very considerable quantities of carbonic acid are habitually formed in thoroughly air-dried soils which have been kept for a long time in dry rooms, either in barrels or in quantities no larger than the contents of an ordinary flower-pot. (See close of Chapter XVI.

"Earth-closets" destroy Manure.

It has been pretty clearly made out that the oxidizing power of dry earth, when loose or not tightly packed, is a matter of no small importance in its bearings upon the so-called "earth-closet" system of disposing of human excrements. In this system, as is well known, the idea is to cover up the excrement instantly with dry earth. Sifted garden loam is best; clayey loam is good; but fine coal ashes will do very well, except that they are rather too dusty for comfort.

There is provided, in place of the fixtures of the ordinary water-closet, a somewhat larger set of pipes for the transmission of powdery earth instead of water, and these pipes are connected with a reservoir of dry earth above. Upon opening a valve, the dry earth flows down as if it were water, and passes into another reservoir below, whence it can be removed from time to time, as occasion may require.

When human excrements are thus covered with fine, dry earth, their odor at once ceases to be perceptible, and no further annoyance can arise from them. All fermentation, in the ordinary meaning of the term, is prevented, and the excrement is deodorized so completely that one and the same barrel of earth may be used over and over again, and finally carted away without offense, precisely as if it were mere loam or ashes, since, except for a suspicion of ammonia, it has no odor other than that of earth. Except for the trouble of keeping up the supply of dry earth, it would be difficult to say too much in favor of this system. As a sanitary device it has very great merit, and is doubtless the next best system to that of water-closets which has yet been devised. One plan was to use charcoal instead of earth, and to carry away the spent material at stated intervals, and "re-burn" it — i. e. subject it to a process of destructive distillation — as a means of maintaining methodically a supply of the absorbent material. (Stanford.)

It was thought at one time that the general adoption of earth-closets in villages and small towns would be a distinct gain for agriculture; for, even if it were admitted that the system is imperfect as a means of preserving manure, it was believed that it must still be vastly better than the methods in common use. Hence it was supposed that an enormous amount of fertilizing material that now goes to waste would probably be saved.

But it is plain, from what has been said already of the mode of action of dry earth, that the earth-closet must be a very imperfect device for saving manure, both because so large an amount of earth has to be used in order thoroughly to absorb the liquid portion of the manure, and because of the tendency of micro-organisms in the earth to burn up and destroy the dung. In point of fact, it has been found in actual practice that the amount of nitrogen retained by the earth is but inconsiderable, even when the earth has been repeatedly used.

Voelcker found in loam which had been used four times in an earth-closet, and dried by fire-heat each time after use, no more than 0.39 % of nitrogen, 1 ½ % of bone-phosphate of lime, and 1⅓ % of potash. At another time he analyzed loam of a somewhat different character, that had been used five times in the closet, and dried by fire-heat four times, and finally been allowed to dry in the air after the fifth use. This material contained 0.41 % nitrogen, 1 % bone-phosphate of lime, and 0.66 % potash. No nitrates could be detected in either of these samples.

Yet again, he analyzed materials from a prison at Wakefield, and obtained the results set forth in the table. For the sake of ready comparison, all the figures are calculated for earth dried at 212°.

	Earth before use.	Earth once used.	Earth twice used.	Earth thrice used.
Organic matter and water of constitution	9.88	9.79	11.53	12.22
Alumina and oxide of iron	12.95	16.15	14.11	12.48
Phosphoric acid	0.18	0.25	0.44	0.51
Magnesia	1.44	2.63	0.77	0.90
Alkalies and loss			0.72	0.74
Insoluble, clay and sand	71.99	68.93	70.30	71.01
Nitrogen	0.31	0.37	0.42	0.51

The original earth was a clayey garden-loam, that contained, when ready for use, 10 % of moisture. The used earths contained from 12 to 22 % of moisture, according to the state of the weather.

It will be seen from the table that there is only a very small increase in the proportion of nitrogen each time the earth is used. The increase of phosphoric acid, though larger than that of the nitrogen, is still small. A ton of the thrice-used earth would hardly contain 10 lb. of phosphoric acid. The once-used earth contained only 0.06 % more nitrogen and 0.07 % more phosphoric acid than the original loam.

In experiments upon a somewhat different plan, made by Dr. Gilbert, 14 cwt. of air-dried clayey loam were sifted and put aside for use. When 0.33 to 0.50 of this store had been used, it was necessary to empty the pit. The mass was found to be uniformly moist throughout, though neither fæcal matter nor paper could be seen in it. This once-used earth was spread upon the floor of a shed to dry, and was then resifted and again passed through the closet. Analysis of the materials gave the following results: —

	Before use.	Once used.	Twice used.
Moisture expelled at 212° F. from the air-dried, sifted soil	8.440	9.970	7.710
Per cent of nitrogen in air-dried, sifted soil . .	0.067	0.216	0.353
Per cent of nitrogen in soil dried at 212° . . .	0.073	0.240	0.383

As Dr. Gilbert has observed, the twice-used soil is no better than good garden-loam. It could not bear the cost of carriage, except to a very short distance. It would appear, nevertheless, from English experience, that when the closets are fed with garden-loam, and the used earth is immediately applied as a fertilizer, crops may derive some benefit from it. When applied at the rate of from half a ton to a ton to the acre, it is said to have been beneficial to grass-land, potatoes, onions, and other vegetables.

Waring's Experiment.

In this country, Colonel Waring, at Newport, purposely kept a couple of tons of the dry earth for a number of years, and had it used over and over again, in order to see how often it could be used without losing its efficiency. The material consisted of a mixture of about 1 part loam and 3 parts coal-ashes. The closets were filled about 6 times a year, and when the vaults were emptied, the earth was thrown into a heap in a well-ventilated cellar to dry. Waring states that the material which he sent to be analyzed must have been used at least ten times, and that it was the same to all outward appearance then as it had been in the beginning. It had no odor, and it looked and felt the same as at first, and it seemed to be just as efficient in the closet as ever.

From Professor Atwater's analysis of this ten-times-used material it appeared that it contained 1.31 % of moisture, 10.72 % of organic and volatile matters, 0.37 % of phosphoric acid, and 0.28 % of nitrogen. It was shown that, excepting a slight gain in respect to phosphoric acid, the material had practically not been improved by its tenfold use. Neither the dung nor the urine with which the earth and ashes had been so often charged had made much impression upon it.

Waring urges that the amounts of these foreign matters added to the earth were by no means small. He computes that the use to which the closets were put was equal to that of four adults for six years; and since an adult voids 23 lb. of dry matter per year in the fæces and 34 lb. of dry matter in the urine, — of which last he admits that one-third went into the closets, — there would be about 34 lb. of dry manure go into the closets every year for each person, excluding paper from the account. Hence the four people in six years would yield over 800 lb. of dry solid manure, containing more than 230 lb. of nitrogen.

From the analysis, it appears that Waring's two tons of material contained only about 400 lb. of organic and volatile matters, some of which was undoubtedly "water of constitution" that would not go off at 212°, and it is to be inferred that a considerable proportion of this organic matter was already contained in the earth at the beginning. Atwater's analysis shows only 11 lb. of nitrogen in the 2 tons of Waring's used earth, which is no more than was contained in 2 tons of the fresh earth (garden loam) analyzed by Voelcker. It would appear that, practically speaking, in this case nearly all the organic matters of the excrement and the paper must have been burnt up and destroyed.

Professor Johnson assures me that he too made analyses of used earth from Waring's closets some years earlier, and that the results were similar to Atwater's. They seemed so extraordinary that Waring could not bring himself at that time to publish them. Of course, the results as now stated are all the more striking, inasmuch as they relate to a longer term of years.

This palpable destruction of manure by dry earth is likely to cast discredit upon one at least of the instances where loam is used for bedding animals. It was formerly thought that, for sheep, bedding with loam must certainly be a commendable practice, since, in view of the comparative dryness of the excrements, there is much less risk than there is with cows of the animals being unduly soiled by contact with the earth whenever it happens to be moistened. But, as has just been stated, there is good reason to believe that this very dryness is a source of danger for the manure.

Composts of Night-soil.

In connection with the subject of the earth-closet, it needs to be said that some of the best of the agricultural methods of treating night-soil have little or nothing in common with the use of dry earth. They are really systems of composting with peat, or loam, or sods. Either enough peat to absorb the urine is occasionally shovelled into a shallow vault, which has been constructed so as to facilitate the addition of the peat and the removal of the mixture, or a considerable excess of peat is strewn at intervals upon the contents of an ordinary vault, and, as often as occasion may require, the mixture is hauled out and thrown up into compact heaps. These heaps are bottomed with peat, and loosely covered with it also, and are then left to ferment.

This method of procedure, there is small need to remark, differs essentially from the dry-earth system. It is nothing more than a particular instance of the ordinary method of composting. The excrement serves as a basis for fermentations by virtue of which the inert matters in the peat are decomposed and converted into new compounds fit for the nourishment of plants. Meanwhile, the antiseptic peat hinders for a time the dung from passing into wasteful forms of fermentation.

It is worthy of remark that, in the country, vaults are objectionable, unless indeed they are very shallow. Not only may they readily become sources of disease, but the process of cleaning them out is always a highly disagreeable task, and sometimes actually dangerous. Doubtless a large part of the prejudice which exists against the use of night-soil is to be credited to the horrible stench which arose from the old-fashioned vaults whenever their contents were disturbed.

Methods of Dealing with Night-soil.

One way of handling the mixture of peat and night-soil above mentioned is to have the receptacle consist of a box or tub, — an old cart-body, for example, — set on a stone-boat or drag, so that it may be hauled into the field without offence, and there be capsized with handspikes. It is still true of such compost, that its odor is vile. Hence good judgment should be exercised as to the times at which to move it, and the fields upon which to put it. In any event, it is well to plough night-soil or blood composts under as soon as may be convenient.

Schmid, in Austria, has described a sensible method of composting night-soil in cases where large numbers of laborers are congregated. If the number of people is moderate, the excrements may be made to fall into petroleum barrels to which cleats or " ears " have been fastened, through which poles can be thrust so that a couple of men may readily lift and carry away the barrels ; or the barrels may be hung permanently on wheels, so that they can be rolled away. At frequent intervals — sometimes once a week, at other times every day — the contents of the barrels are thrown into a pit or basin and covered with a thin layer of crumbly peat or of peat-moss ; the rule being to add enough peat that moisture shall no longer be seen at the surface of it. An automatic arrangement for strewing the peat thinly and evenly has been found to do excellent service.

From the basin, the material is hauled directly to the fields, and strewn there at once with forks and shovels, or from a manure-spreader. Six or eight wagon-loads of this compost are held to be as powerful as 20 or 25 loads of good farmyard-manure. The oftener the compost can be hauled away from the basin the better, since the pressure exerted by the upper layers of the mixture tends to supersaturate the lower layers with moisture.

In a case where the contents of a pit were removed at the end of 3 months, the lowest layer was found to be soft and foul-smelling, while the upper third of the heap gave off but little odor, and was in a highly satisfactory condition. This method of procedure admits of being applied in the case even of thousands of workmen, in buildings several stories high, if only the excrement is made to fall through straight pipes into iron barrels set upon wheels.

Considerable quantities of night-soil are still hauled out from some parts of Boston to be used as manure, most of it being in the condition of a thick, muddy liquor; though some fresh solid dung is brought out, and the farmers very much prefer this material to the liquid, which has always undergone more or less decomposition or dilution.

Forty or fifty years ago, when the employment of night-soil was more common, or at the least more conspicuous, than it is now, the plan was sometimes adopted of allowing the liquid to run out upon the land to be cultivated, where it soaked into the soil, and was subsequently worked in by processes of ploughing and harrowing. But a more common plan was to prepare a compost bed at the edge of the field, by ploughing up a patch some twenty or thirty feet in diameter and making a rim of earth a foot or so high around it. The night-soil was allowed to flow into and fill this basin, where much of it soaked into the earthen floor and some part of the water evaporated. Loam, or well-pulverized peat that had been exposed to the air for a year or two, was then thrown upon the surface of the mud, together with plaster of Paris in many instances, and when the matter was dry enough to handle, it was forked over, sometimes twice, as a preparation for its distribution upon the fields. The farmers who made these composts preferred them to fresh night-soil, and found that they did good service. Probably large quantities of nitrates were contained in the finished products. The use of plaster in this case seems commendable.

One method of applying night-soil, in use in Europe, is to scoop out, at appropriate distances from one another in the field to be manured, a number of shallow holes or cups two or three feet in diameter, to run the liquid night-soil into these holes, and to throw it from them upon the surface of the land.

Real Danger of Night-soil.

It was thought formerly that various chemical substances prejudicial to health are liable to be produced by the decay of human excrements, and that the dangers which are known to arise from keeping excrements stored in vaults, or from allowing them to soak into the earth around dwelling-houses, must be attributed to this cause. Nowadays, rather less importance is attached to this old conception, although it is still recognized that there may be something of truth in it. Perhaps it is only under quite exceptional conditions that any serious danger to health can arise from the chemical products of decaying night-soil.

The real trouble seems to be, that excrements do at times serve as the home and breeding place of certain microscopic organisms, one or another of which may cause a particular disease, — such, for example, as dysentery, typhoid fever, cholera, or diphtheria. It is only when the special microdeme which occasions one of these diseases is present in the night-soil, or in the earth or water into which night-soil has soaked, that there is any great danger in having it about. Nevertheless, it may often happen that night-soil will contain less noxious, though still hurtful organisms, such as might occasion diarrhœa, or cause inflammation to set in upon any trifling cut, or scratch, or abrasion of the skin, with which a little of the night-soil, or emanations from it, may have come in contact. All this beside the depressing effect of the offensive odor, which, for some organizations, might be sufficient to predispose the system to disease. (See subsequent chapters for Night-soil and Sewage.)

It is to be noted withal that special dangers may lurk in other kinds of manures beside night-soil. Thus lock-jaw (tetanus) is now thought to be caused by a microbe which may come to us in some way from the horse. Several instances are upon record in which men have died from lock-jaw after having been wounded by pieces of iron which had been soiled with horse-manure, and even when straw thus soiled was rubbed against a wound; and epidemics of lock-jaw have occurred in hospitals in which wounded men were exposed to emanations arising from heaps of horse-manure.

CHAPTER XXI.

MODES OF APPLYING MANURE.

WITH regard to the methods of applying manure to the soil, it is extremely difficult to lay down general rules applicable for all cases. But there are still some things which may be said. It is easy, for example, to object to a system which prevails somewhat in the vicinity of Boston upon gentlemen's estates, of spreading farmyard-manure upon the surface of lawns in late autumn or early winter, in such positions that some part of the goodness of the manure must be washed away by every rain that falls upon the frozen ground.

The objection here is simply from the chemist's point of view. It may be possible, perhaps, that the custom has its advantages, both as a means of maintaining a thick stand of grass and of saving labor, though the probabilities are that it has been imported from a mild European climate, and applied here thoughtlessly. It seems but reasonable to maintain that winter top-dressing should be restricted to level fields, for both rain and melted snow may sweep manure from frozen hillsides before its constituents can have had any fair chance to soak into the earth.

Spreading Fresh Manure.

The practice of carting out fresh manure from the barnyard as fast as it is made, and spreading it directly upon the fields, even in winter, has frequently been advocated abroad, and has been commended by several good farmers even in New England, though it may be doubted if they were hill men. The chief gain, no doubt, is in the saving of labor. Indeed, it can well happen that the farmer may find so much advantage in having his teams and men haul out and spread manure at an idle season, in order that they may be free for other work when it presses, that he can afford to put up with considerable losses of manure in the field, no matter whether they be caused by sweeping rains or by hurtful fermentations. It must be remembered withal, that the manure would have probably suffered some loss anyway, even if it had been left in the barnyard.

The spreading of short manure upon grass early in the autumn or even very early in the spring, is no doubt commendable in many situations, as a means of maintaining the field in good case;

and, as has already been insisted, the surface spreading of manure in temperate climates, like that of England, may be really advantageous, even in winter, since the unfrozen ground absorbs much of the goodness of the manure. Chemists are prone to believe that the formation of nitrates from the nitrogen-compounds of the manure will be promoted by surface spreading, and that these substances may remain inert and unacted upon when buried in a soil of close texture.

One objection to the system of surface spreading, true especially of light, leachy soils, is that the non-soluble portions of the manure, as they lie upon the surface of the ground, are liable to dry out to a peat-like substance, which probably exerts very little, if any, useful effect upon the growth of crops. It has been noticed on the Continent of Europe that farmyard-manure may be applied in the spring to help forward a grain-crop which has suffered from the winter's cold, provided the grain has been sown in drills so that the cultivator can be used to put a light covering of earth upon the manure. Otherwise there would be a risk of the manure's being dried out by sun and wind to such an extent that the crop might not be benefited by it in the least.

Best Depth to bury Manure.

It seems plain that, as a general rule, manure should be buried to such a depth that it may be kept damp by the capillary and hygroscopic moisture of the soil; while, at the same time, no very large proportion of the manure should be buried so deeply that air cannot gain access to it. Both these considerations naturally point to the conclusion that it will usually be proper to bury manure deeper on light land than on heavy land, though the depth will necessarily vary in different instances, according to the climate and the relation of the soil to the ground-water. It might well be modified accordingly as the season was to be wet or dry, if the event could but be predicted. It may often happen that a summer shower will moisten the surface soil sufficiently to thoroughly soak the manure there situated, while only the heavy rains of autumn or spring might reach manure that had been deeply buried.

As for the lower soil, it is of course important, if the tilth is good, that there should be in it an abundant store of plant-food; but it is probable that in most instances this deep-lying food had better consist of inorganic matters that have been fixed or absorbed by the earth, or of nitrates that have soaked downward, rather than be in the form of barnyard-manure. To gain this end it would seem to be good policy to turn under a soil which has borne heavy crops since it was manured and to manure afresh the soil, formerly buried, which has been brought to the surface by this operation, rather than try to bury fresh manure deeply at the start.

The importance of a store of deep-lying plant-food to serve as a safeguard in times of drought has been well shown by some experiments of Lawes and Gilbert on top-dressing hay-fields. In a year (1870) which was characterized by a term of drought which began at a time when vegetation usually becomes active and lasted with little intermission until autumn, it was observed that grass which had long been manured with a mixture of nitrate of soda and mineral fertilizers gave excellent crops of hay, while contiguous plots — even those liberally dressed with stable-manure from London — yielded so little grass that they were hardly worth mowing. The significance of the nitrate will be seen on glancing at the following table in which are given the numbers of cwt. of hay harvested from the acre of land in three selected instances :—

Kind of Manure.	Cwt. hay in 1870.	Average crop per year from 1856 to 1870.	Deficiency in 1870. Cwt.
No manure	5.75	22.75	17.00
Mixture of mineral fertilizers and ammonia salts	29.50	52.38	22.88
Mixture of mineral fertilizers and nitrate of soda	56.25	57.63	1.38

On the unmanured plot, the drought of 1870 reduced the crop of hay to about one quarter of the average yield; the product this year was less than had been harvested in any preceding year of the fifteen.

On the plot manured with mineral fertilizers and ammonium salts — the ammonia of which tends to become fixed in the surface soil — a considerable crop of hay was harvested in spite of the drought, though the yield was much less than in ordinary years.

But on the plot dressed with nitrate of soda and minerals, a heavy crop of hay was obtained and the grass evidently suffered but little from the long continued dry weather. Thanks to the easy diffusibility of the nitrate of soda, this fertilizer had penetrated deeply into the soil during all the years of the experiment, and grass-roots had followed it to such an extent that when drought set in these roots were far better able to obtain water than the finer and much less vigorous roots in the unmanured land.

Even on the plot dressed with mineral fertilizers and ammonia salts where — thanks to the abundance of plant-food — free-growing grasses predominated, the habit of growth of the roots was such that the plants were in great measure dependent for their supplies of food and moisture on what could be found in the upper layers of soil.

It is true of course that different kinds of grasses grew on the different experimental plots, according as the manures differed. It was observed, for example, that while the grasses most encouraged by ammonia salts have a tufty habit of growth above ground and a tendency to luxuriate within a limited range beneath the surface, some of those most favored by nitrate of soda grow close together and send down strong wiry roots far into the subsoil.

But the fact remains none the less that the store of deep-lying manure was of enormous advantage in enabling the grass to withstand the drought. It was found, in fact, on determining the amounts of moisture contained in the soils of the several plots, that the grass on the nitrated field had really obtained large quantities of water from the clayey subsoil. It was made manifest that this grass had pumped out the land drier and to a greater depth than could be accomplished by the herbage of either of the other plots. That is to say, the nitrated grass was able to find water and to use it with advantage at a time of direst need.

These experiments enforce, furthermore, the lesson that for almost every kind of crop there must be some one depth of burying the manure which will be better suited, on the whole, than any other for that special crop; for the roots of different kinds of plants are very unlike, both as regards their bulk or quantity, and their behavior or requirements. Most of the grains, for instance, send out feeding roots in all directions, and so do the different kinds of clover. With carrots and parsnips, or lucern, for example, there will be little risk of burying manure too deeply.

It would be well for every farmer to determine some of these points once for all for his own soil, by dividing the fields into fractions, and burying portions of the manure at different depths upon the several fractions.

Experiments on burying Manure.

There is an interesting series of experiments bearing upon this point, which were made under the auspices of the Massachusetts Society for Promoting Agriculture, many years ago. The idea was to divide a field into five equal parts for a rotation of three years. Four of the plots were manured, but the fifth was not.

The manure on the first plot was ploughed in to a depth of eight inches; that on the second plot to a depth of four inches; and that on the third plot was merely harrowed in, while upon the fourth plot the manure was spread upon the surface of the ground. The results of the experiments have been published, and are well worthy of being carefully studied, though they teach no precise lesson. Doubtless each one of these experiments — and they were made by different farmers scattered throughout the State — must have been exceedingly valuable to the person on whose land it was made, as well as to those neighbors who happened to have land similarly situated.

In these experiments it appears that, in general, deep ploughing (8 inches) answered best for grain, while Indian corn profited most from the manure that was merely harrowed in. Hay did best with manure buried four inches; and, on the whole, so far, be it well understood, as these experiments go, this depth of four inches would seem to be the best, in case the farmer were to be compelled to confine himself to any one depth for all crops and soils. Next to 4 inches, the depth obtainable by harrowing was found to be best on the whole; and it is to be remarked that this result tends to support the practice of those farmers who prefer to wait until their land has been ploughed and then to apply the manure and harrow it in thoroughly, instead of plowing under the manure at first. In the column of final averages, very little can be found in favor either of deep ploughing or of top-dressing. Even with guano, top-dressing has been found inferior to ploughing under.

It is noteworthy in these experiments that the character of the crop seems to have had far more influence upon the results than the character of the soil. For grain, however, the deep-buried manure did best, upon the whole, on the heavy soils; while upon the light soils the shallow-buried manure did better than the deeply buried. Manifestly, the results are complicated by the question whether the ploughing may not have done good in itself. In a few instances, the manure which was spread upon the surface of the light soil did best of all.

In judging of any such experiments as these, the operator will need to view the field with knowledge. That is to say, knowledge as to the position of the ground-water and as to the capillary condition of the soil, as well as of its power of holding rain-water. He will naturally notice also the chemical character of the humus, and whether or not the conditions are favorable for nitrification.

Manure should be well worked in.

No matter at what depth manure is to be buried, it is of importance to secure an equable distribution and dissemination of it in the soil in order that all the plants in the field may be equally well fed and an even stand of the crop secured. Moreover, it is a matter of familiar observation, that, when a lump of manure of any considerable size is buried in the earth, it is apt to remain undecomposed for a long while, and to be found as a lump perhaps even years afterward. It is to avoid this result that farmers take so much trouble to fork over manure repeatedly, and to use it whenever possible in a well-rotted, "short" condition. Various improved harrows, of recent invention, are valuable aids for working manure into the soil evenly and effectively. One way of helping to admix manure with the soil is to haul out and spread the manure roughly upon sod-land in the winter and early spring, and to pulverize the clots of manure, just before ploughing, by going over the land with a bush-harrow.

Much might be said in favor of ploughing in manure in the autumn as a preparation for the next year's crops. On light, thirsty lands, this course obviates the necessity of losing moisture by stirring the soil unduly in the spring; and on clays it is generally admitted that ploughing and manuring in the autumn are beneficial for the tilth of the land, to say nothing of avoiding the trampling and pressure which would occur if manure were hauled upon the land and distributed in the spring. Moreover, the fertilizing materials have opportunity to become pretty thoroughly incorporated with the soil, and the spring work is lightened. This method is often practised in England in preparing land for root-crops, and it has been urged as one of its advantages that the manure is kept out of the way both of the seeds and of the roots. Mangolds, for example, are apt to be injured in shape and in value from the bulbs coming in contact with the straw and clots of manure that has only recently been ploughed under. One good rule with regard to the burying of manure is, that the aim should be always to fill the staple with plant-food.

The following table contains the results of Dehérain's experiments on growing fodder-corn (maize) on a light, somewhat calcareous soil, on one part of which farmyard-manure had been buried, while on another part the manure had been spread upon the surface of the land: —

40,000 kilos. of manure.	Kilos. of crop harvested. 1878.	1879.
Buried	78,000	87,000
Spread	71,600	58,000

A somewhat similar result was obtained in experiments on potatoes, though the differences were in this case much less strongly marked. It was found, too, that the unexpended residues of the buried manure gave a much better crop of wheat the next year (and of sainfoin, also) than did those left by the top-dressing.

Manure may ferment the Soil.

Beside the main points of placing the manure where it can be got at by the roots of plants, and kept moist for their sake, there are some other considerations of a chemical nature which bear upon the question of burying manure. Doubtless it often happens that farmyard-manure, and other substances rich in organic matter, may do good work by bringing about quick fermentation in the matters of which the soil is composed, whereby the inert nitrogen of the humus, as well as various inorganic substances, are decomposed and made available for the plant. But in order to effect this kind of fermentation, the manure must at the least be covered by the soil. Upon light land, in a dry season, the manure would have to be buried tolerably deep, in order that it shall not dry up and be powerless to induce the fermentations now in question. Here, by the way, is a capital distinction to be made between manure, properly so called, and compost. Composts can hardly be expected to excite active putrefactive fermentation in the soil, such as dung would excite.

It is to be presumed that the first fermentation which occurs when fresh manure is buried in the soil will be ammoniacal. Marchal has discovered, in fact, that ammonia is produced in a solution of albumen by the action of several of the micro-organisms which occur in ordinary soils. Even yeasts and moulds, acting upon albumen or the like, can produce ammonia. Muntz and Coudon mixed several kinds of soils with dried blood, and, after having sterilized the mixtures at 248° F., they "seeded" some samples with unsterilized loam, while other specimens were left unseeded. All the mixtures were then moistened with water and were left at rest, shielded from the air during several months. After the lapse of 67 days, there was found in 100 parts of a "seeded"

Calcareous soil from Champagne . . .	0.111 part of ammonia.
Garden-loam	0.059 " " "
Moor-earth	0.041 " " "

while no ammonia formed in the unseeded sterilized samples, not even in the course of 2.5 years.

On the other hand, the formation of nitrates from the nitrogenous components of the manure and the soil is a very important consideration, and it is precisely here that the composts are more likely to do good than the dungs. It was customary, formerly, whenever a new saltpetre-bed was established, to bring some earth from an old bed and mix it with the new materials. This old earth was called the "seed-petre" or "mother of petre," and was, as we now know, charged with the nitrifying ferments. But, in a precisely similar sense, a well-prepared compost may be regarded as a nest of ferment organisms proper to cause nitrification of the humus of the field. The idea is, that, as regards nitrification, the compost is likely to act more quickly than fresh dung; though the dung might of course favor nitrification after its first hot fermentation is spent.

As was just now said, Dietzell has observed that considerable amounts of free nitrogen may be lost from manure after it has been incorporated with the soil, in consequence of the formation of nitrites by way of fermentation. He urges that this waste of nitrogen may be checked by applying, together with the manure, a quantity of superphosphate or of precipitated phosphate of lime; or better, by putting one or the other of these materials upon the dung-heap, during its formation, at the rate of one pound of phosphoric acid to 800 lb. of the dung. It was shown long ago, by Voelcker's observations on the composition of waters discharged from fields through tile-drains, that nitrates are gradually and constantly formed from the slow decomposition of farmyard-manure in the soil, i. e. through the oxidation of the nitrogenous constituents of the manure.

Leachy Soils.

It is to be presumed that the popular opinion that manure should not be buried deeply in light soils is true, because of the property of such soils to facilitate the formation of nitrates from the manure applied to them. It is hardly to be believed that such soils are called "leachy" because of an idea that the ordinary soluble constituents of manure can be washed out of them by rain, for the power of the double silicates in the soil to hold these constituents of manure is very great. But within these porous soils nitrates are doubtless formed rather freely, and, as is well known, the nitrates are easily washed out from soils, and are liable to go to waste after every rain that is long continued. They are, in fact, leached out of the soil, and the manure from which they come rapidly wastes away. It is said to be a matter of old and familiar observation in Germany, that in sandy regions, in seasons that are particularly wet, the soil may finally be leached so thoroughly that it becomes unfruitful. Under these conditions, tobacco, in particular, according to v. Babo and Nessler, is seen sometimes to suffer from actual starvation.

On the other hand, it is possible that one reason why manure had better be kept near the surface of light land is that nitrates are formed more readily in that position than at a greater depth; as, for example, in the case of the manure that was harrowed in for corn in the experiments of the Massachusetts Society above mentioned. Practical men maintain, as a general rule, that manure has but little endurance on light soils, especially on those which are calcareous. They find that the fertilizing effect of it soon ceases to be manifest unless the dressings are frequently renewed.

Composting the Field itself.

Just as in the preparation of compost-heaps, so in the burying of dung there are two tolerably distinct conceptions to be kept in view. Beside nitrification, there needs to be considered the precedent fermentation of the humus of the soil, which, under farming conditions, may be produced when dung is incorporated with the loam of a field almost as readily as when it is mixed with similar humus in the compost-heap. It may often happen that this first fermentation may be produced much more economically by ploughing under dung in the field than by establishing regular compost-heaps. In seeking to accomplish this kind of result, the farmer may either plough under fresh farmyard-manure, or he may top-dress his grass or fallow-land with almost any kind of fertilizer some time before he means to plough, in order to encourage a rank growth of grass or weeds, which, on being turned under, will speedily ferment.

Heat of Fermenting Manure.

It is the market-gardeners in particular who esteem heavy dressings of horse-manure on land moist enough to be well insured against risks from drought. They find their advantage, also, in early spring, in making use of the warmth which fermenting horse-manure communicates to land upon which early vegetables are to be grown. This point has been studied by Wagner. He found, when the temperature of the air was no lower than 50° F., that the temperature of the soil could be increased to an appreciable degree by working into it stable-manure. The warming is specially well marked when the manure is highly nitrogenous, and in a condition fit for rapid fermentation, when large amounts of it are used, and when the soil is not too wet. An addition of materials competent to hasten fermentation, such as barnyard-liquor for example, notably increases the elevation of temperature. So does an addition of lime, though much less emphatically. Most heat is developed immediately after the manure has been buried, though the evolution of heat may persist for some time when the external conditions are favorable. Thus, on land dressed with from 40 to 44 tons of horse-manure to the acre, warmth may be imparted to the soil during periods of from 4 to 12 weeks (or more), and the increase of temperature may range from an amount which is barely perceptible to as much as 1° of Fahrenheit's thermometer. On the average, it amounted to from 0.2° to 0.7°, in these experiments. The best mean increase of temperature for a fortnight was 1°. The maxima of increase observed by Wagner, as imparted to the soil by bean-straw (wet with barnyard-liquor?) and fresh horse-manure respectively, were 5° and 2°. As everybody knows, the heat of fermenting horse-manure has been utilized by gardeners from time immemorial for starting hot-beds in frames and greenhouses.

Muntz and Girard have noticed, during the first few days of fermentation, that heaps of horse-manure may get hot enough to mark 176° F., and that they may remain for a long while as hot as 158° F. Cases are upon record, indeed, in which heaps of horse-manure have spontaneously burst into flame. Georgeson, at Tokio, sunk in a field a number of bottomless frames, of equal size and each one foot deep, so that their rims were level with the surface of the soil. He filled these frames with the light, porous, volcanic, ash-like soil of the locality, which contains naturally 7 or 8 % of humus, and he incorporated with the earth various quantities of partially decayed manure that was still rather long. A thermometer was buried in each of the mixtures, 5 inches deep, and all of them were left exposed to sunshine and rain in the open field. The thermometers were observed from Oct. 27 to Nov. 22, 1886, and the averages of the readings divided into five-day periods are given in the following table: —

Manured at rate per acre of	80 Tons.	40 Tons.	20 Tons.	10 Tons.	No Manure.
Temp. of 1st Period (Oct. 27 to 31)	65.1°	63.1°	63.8°	62.5°	60.5°
Excess of temp. over no manure	4.6	2..6	3.3	2.0	...
Temp. of 2d Period (Nov. 1 to 5)	62.2	61.3	60.2	59.5	58.5
Excess over no manure	3.7	2.8	1.7	1.0	...
Temp. of 3d Period (Nov. 6 to 10)	60.4	59.3	58.4	57.8	57.2
Excess over no manure	3.2	2.1	1.2	0.6	...
Temp. of 4th Period (Nov. 11 to 15)	56.8	56.2	55.3	54.8	54.7
Excess over no manure	2.1	1.5	0.6	0.1	...
Temp. of 5th Period (Nov. 16 to 22)	52.5	51.6	50.1	49.8	50.8
Excess over no manure	1.7	0.8	—0.7	—1.0	...

The temperatures diminished so regularly in proportion as the earths contained less dung that it seemed manifest that, if it were but possible to control precisely all the conditions of the experiment, the amount of heat received by the soil would be in direct proportion to the amount of manure applied. The explanation of the minus quantities given in the table is that, when the manure had been converted to humus, the capacity of the soil to hold water was increased, and evaporation from the soil became larger and more constant, so that the soil became cooler than the drier, unmanured soil.

The fact was remarked upon long ago, by European farmers, when sheep were folded upon meadows in late autumn and early winter, that the grass continued to grow green and vigorous in spite of the advent of weather cold enough to kill all the grass on neighboring fields. Where the sheep had been folded, the grass looked as if water from a spring had flowed upon the land. So, too, on mountain pastures, above the tree limit, luxuriant patches of grass continue to grow until the advent of very cold weather, on the spots where cows were milked during the summer.

Of course the condition of the land must be favorable both for the fermentation and for the growth of plants. As Tull remarked:

"The action of the dung's ferment affords a warmth to the infant plants in their most tender state and the most rigorous season. But though dung, in fermenting, may have a little warmth, yet it may sometimes, by letting more water enter its hollowness, be in a frost much colder than undunged pulverized earth."

Modes of applying Artificial Fertilizers.

What has been said above, refers, of course, mainly to the burying of farmyard-manure. In respect to the artificial fertilizers, it can be said tolerably well beforehand what needs to be done in order to secure their proper diffusion and distribution in the soil. For example, nitrate of soda may be simply scattered on the surface of the land, for it will readily dissolve there and soak into the soil. Sulphate of ammonia, bone-meal, oil-cake and fish-scrap need to be buried tolerably deeply, in not too dry earth, that they may nitrify readily. Bone-ash, bone-black and phosphatic guano need to be buried pretty deeply, and to be commingled with the soil. With them, as with potash salts, it would be well, were it not for the trouble involved, to apply one portion of the dressing before ploughing the land, another before cross-ploughing it, and another before harrowing, to insure thorough distribution. Even as regards guano and superphosphate of lime, it has been found best to work them into the soil as thoroughly as may be practicable, by mechanical means.

Merit of thorough Dissemination.

In experiments made by Funke, a mixture of high-grade superphosphate of lime and sulphate of potash was spread upon the surface of one part of a field of moderately deep loamy clay, while upon another part of the field these fertilizers were plowed under at a depth of rather more than 8 inches. The land was naturally well adapted to clover, though it stood in need of being re-seeded; it was ploughed and fertilized in the autumn, and left lying in rough furrows until the next spring, when clover was sown upon it. A third part of the field received neither of the above-mentioned fertilizers; but strips of land running across the field were dressed respectively with common salt, nitrate of soda and gypsum, in the hope that one or the other of these substances might perhaps serve the purpose of dissolving and distributing the phosphate and the potash. It appeared that the lightly buried manure served best to start the young clover, and that during the first year a better crop was got from this part of the field than from the other. The very first cutting of clover, in particular, was decidedly better on the land where the fertilizers had been simply strewn. But in the second year a very different result was obtained, and it then appeared that much the best crop grew upon that part of the field where the fertilizers had been ploughed under.

It may be said, indeed, that, generally speaking, it has been found to be advantageous on rich land to bury rather deeply even the soluble artificial fertilizers, especially in cases where they are used to force heavy crops. That is to say, the absorptive power of some soils is so great, and the advantages of thorough dissemination are so real, that the utmost pains should be taken to secure the best possible distribution in the soil of all kinds of fertilizers. Petermann has shown, by numerous trials made in a good, sandy, clay loam, that for beet-roots it is best to bury deeply, and to thoroughly incorporate with the soil even sulphate of ammonia and nitrate of soda. He found that the largest crops were obtained when these (and other) fertilizers were spaded into the soil. Smaller crops were harvested in the cases where the fertilizers were raked in, or harrowed in, or hoed in. He noticed, also, that when the fertilizers were drilled in with the seeds they hindered the germination of the seeds. In the absence of rain, he says, and at a time of drying winds, this retardation might seriously injure the crop. But, even with the best of weather, the beet-seeds drilled in with the fertilizers did not give so good crops as were got from seeds that were drilled in after the fertilizers had been buried.

A synopsis of Petermann's results is given in the following tables. The experiments of 1881 were upon garden plots of 23 square metres, which had all been spaded in April. The manured plots were dressed, at the rate of 880 lb. to the acre, with a mixture of nitrate of soda, chloride of potassium, and precipitated diphosphate of lime. That is to say, each plot received 2,300 grm. of the fertilizer, which contained 3.69 % of nitrogen, 6.39 % of potash, and 6.21 % of phosphoric acid.

In 1881 the following crops were harvested: —

Treatment of the Plots.	Kilos. to the Hectare.	Increase of Crop.	
		Kilos.	Per Cent.
No fertilizers	17,657	. . .	. . .
Fertilizers raked in	22,950	4,933	27.9
" hoed in 4¾ in. deep .	32,674	15,017	85.1
" spaded in 8¾ in. deep .	38,543	20,886	118.3

The crops of 1882 were as follows: —

No fertilizers	21,772	...	...
Fertilizers raked in	22,453	681	3.1
" hoed in 4¾ in. deep	36,217	14,445	66.4
" spaded in 8¾ in. deep	39,030	17,258	79.3

The manure of 1882 differed decidedly from that of 1881 in that it contained a quantity of organic nitrogen and of ammonia-nitrogen, as well as of nitrate-nitrogen. It consisted of a mixture of dried blood, sulphate of ammonia, nitrate of soda, chloride of potassium, superphosphate of lime and precipitated diphosphate of lime. It was applied to garden plots at the same rate as in 1881, and contained 2.05 % organic nitrogen, 1.98 % ammonia nitrogen, 1.52 % nitrate-nitrogen, 5.18 % potash and 8.94 % phosphoric acid.

The final trials of 1883 were on fields dressed with 500 kilos nitrate of soda (with 15.53 % nitrogen) to the hectare and 650 kilos of "superphosphate" (with 14.51 % of phosphoric acid soluble in citrate). The averages of the results were: —

	Roots to the Hectare, in Kilos.	Tops to the Hectare, in Kilos.
No fertilizers	49,310	24,722
Fertilizers harrowed in	58,547	31,625
" spaded in 4.75 inches deep	65,726	34,675
" spaded in 8.66 inches deep	69,596	37,243
" drilled in under the seeds	61,392	38,795

These results have been confirmed by, Guinon in France, who harvested 23,560, 27,020 and 31,400 kilos. of beet-roots respectively, from land into which chemical fertilizers had been worked to depths of 4, 6 and 8 inches.

As long ago as 1850, at the time of the discovery of the chemical fixing power of soils, Lawes assured Professor Way that, although he had taken great pains to use the best drills in applying artificial manures to his experimental fields, he was constantly reminded of the inadequate distribution of the fertilizers by the irregularity of the crops. Berghe, also, in experiments with potatoes on a light sandy soil, got decidedly better crops — both as regards quantity and quality — by burying mixed artificial fertilizers to a depth of 9 inches than were obtained by applying similar fertilizers to the surface of the land. When nitrate of soda was used as the source of nitrogen, the increase of crop due to burying the fertilizers amounted to 5 %, while there was a gain of 10 % in cases where sulphate of ammonia was employed.

Why Dung and Urine are Pre-eminent.

There can be very little doubt, after all has been said, that one chief reason why farmyard-manure retains so very prominent a position is that people know pretty well how to use it. Another strong point in favor of farmyard-manure is the general applicability of it. For inasmuch as such manure contains all the ash-ingredients of the plants from which it has been formed, and a fair proportion of their nitrogen also, it is necessarily a mixture of things needed by living plants. More than this, it is a mixture in which the several ingredients are tolerably well proportioned to the demands which will be made by the plants.

It is true, as has been already insisted, that, in one sense, the excrements of animals might seem not to be precisely equivalent in value, as manure, to the food consumed by the animals in producing it. A ton of clover, for example, buried in the ground, might put into the land more nitrogen, and perhaps even a somewhat larger proportion of ash-ingredients, than could be got by feeding out the clover to cattle, and carrying their dung and urine to the field. And instead of "clover," in this statement, the name of any other article of food might be put. In the case of young, growing animals, and that of milch cows or of sheep, the difficulty is aggravated, as has been shown; but in no case is it wholly absent. From numerous experiments made by different chemists, it appears that, on the average, little more than four-fifths of the nitrogen consumed by stabled animals in their food can be carried to the fields in the form of liquid and solid excrements. The rest not only serves to form milk, and flesh, and wool, or the like, but the major part of it is dissipated by processes of decay and putrefaction.

Excrement better Manure than Food is.

It was on account of this waste, part of which he wrongly supposed to be due to respiration and perspiration, that Boussingault once threw out the suggestion that, in one point of view, cattle might fairly enough be regarded, not as producers of manure, but as consumers (i. e. destroyers) of manure.

Still earlier than Boussingault, the German chemist Sprengel entertained a similar idea, and he made experiments to prove it. Starting from the crude notion that the fodder which passes through an animal cannot become "animalized" by the act of thus passing, it was urged that a given weight of food applied to the land as such must produce a greater fertilizing effect than a similar weight of food after it has been fed to an animal, and thereby changed to excrement.

To test this hypothesis, Sprengel fed one parcel of fodder to fatting sheep, and at the same time he prepared a heap composed of another equal parcel of the fodder, to which he applied as much water as was given to the sheep. Naturally enough, his heap of fodder weighed a good deal more than the excrements of the sheep, and on contrasting the two products by applying them for the fertilization of potatoes, the uneaten fodder gave a larger crop than the dung.

Both the remark of Boussingault and the experiment of Sprengel are interesting and instructive, as exhibiting one view of the subject. But the idea which they seek to express can no longer be accepted as true, in a practical sense. For the chemical constituents of dung are very different from those of plants. Contrary to Sprengel's teaching, fodder *is* "animalized" as it passes through the body, in that the best part of it becomes part and parcel of the body before it is sent out, or expelled in the secretions, in the form of urea, and of hippuric and uric acids. For that matter, the difference in the fertilizing action of dead plants and of manure is well illustrated by the fact of observation that, while grain grown after a green-manuring is not specially liable to run to leaf or to lodge, there is great danger that both these mischances may happen when manure is applied directly for a grain-crop. Excrements resemble dead flesh withal, in that they afford fit residence for various ferment organisms which bring about decompositions unlike those which occur commonly in the decay of plants. Doubtless the English farmers were right, when, as will be set forth on another page, they were willing — at times when cattle were costly and turnips abundant — to give their turnip-crops to any one who would bring stock to consume them upon the land.

Dung and urine not only bring to the soil matters directly assimilable by plants, which are of the utmost value as plant-food, but they excite fermentations in the earth, which, as all experience shows, are useful for the growth of plants. Hence, in spite of all the sources of waste above mentioned as incidental to its formation, farmyard-manure is a tolerably complete fertilizer. By applying it to the land in sufficient quantity, plants can be supplied with everything necessary for their growth.

As regards the ordinary run of soils, there are few among the commercial fertilizers of which the foregoing remark can be made. Nor is it strange that this should be so, for the commercial fertilizers have come into use as additions to or re-enforcements of stable-manure. They originated in countries where the farms are based upon the keeping of cattle, and have found their chief use in connection with stable-manure.

Hitherto, the artificial fertilizers have, for the most part, been applied in conjunction with dung, to supplement it; or, perhaps even more commonly, one or another of them has been used to force some one particular crop in a rotation the fundamental basis of which is farmyard-manure. It is only comparatively recently that the commercial fertilizers have found extended use in the cultivation of special crops, such as cotton, sugar and tobacco, and people were singularly slow in grasping the idea that mixtures of the artificial products were needed in order to compete with dung.

Farming possible with Artificial Manures.

It is because of the facts above stated that books relating to practical agriculture still lay so much stress upon farmyard-manure, and have so little to say about the practicability of carrying on farms by the exclusive use of commercial fertilizers. Indeed, comparatively speaking, very little information upon this point has ever been published. The experience of many years will be needed, moreover, before any one can say with certainty whether a given course of husbandry is permanently profitable. At the very worst, however, there would seem to be no real difficulty in maintaining a farm in good heart by means of the commercial fertilizers now procurable, if they were used in connection with some system of green manuring, or with composts made of vegetable matters fermented with night-soil, soap-boilers' scraps, or alkali; for in these ways, if in no other, manures of general applicability could be obtained proper to replace the dung of animals. This idea is in some sort foreshadowed by an old Irish method of obtaining manure by rotting hay. On the banks of the Shannon, where much natural grass is mown for hay, small patches of the standing grass were formerly bought by the neighboring cottagers, even by those who kept no live stock, for the purpose of obtaining manure for their potato-beds. The hay was put into a hole near the cabin, and house-slops and all manner of refuse were thrown upon it to hasten the process of decay.

When the preparation of composts comes to be properly understood and methodized, it may perhaps be found to be true universally, as it is now of cattle-farms, that the best way of employing the chemical fertilizers is in small quantities, as helps to the general manure obtained by the decomposition of vegetables.

On good moist land, a little bone-meal, castor-oil-cake, cottonseed-meal, nitrate of soda, or superphosphate, used in connection with farmyard-manure, will often exert an influence out of all proportion above the cost of the addition.

Use of "Artificials" to produce Dung.

Upon some of the grain-farms of Europe, it was formerly held that the true theory of the use of commercial fertilizers was, that they should be employed in quantity just sufficient to increase the product of fodder and straw to the extent that a sufficient number of animals might be kept to supply dung enough to manure the farm richly and completely. This theory has merit, as far as it goes; but it fails to recognize and allow for a certain deficiency of active nitrogen which is inevitable in farmyard-manure. One of the chief merits of nitrate of soda is that it can supply such crops as grain and sugar-beets with easily assimilable nitrogen in the spring, at the time of their greatest need. At that season, farmyard-manure which has been applied to the land often fails to nitrify fast enough — either because the ground is too cold or too dry — to supply the demands of the growing crop. And the remark is doubly true of unexpended residues of previous manurings which may have been left in the land.

Special Manures sufficient in certain Cases.

There are exceptional soils and districts so fertile naturally that they do not stand in need of complete manures. There are many localities in Europe and elsewhere where potash, at least, seems to be abundantly supplied by the soil. Upon some of the intervales of New England, even, and upon reclaimed salt-marshes, some one special manure might perhaps be used year after year without exhausting the land. Discretion must, of course, be used in such cases, as always in the application of concentrated manures. But it is to be remembered, on the other hand, that there is no system of farming more unphilosophical, chemically speaking, than that which insists on piling stable-manure year after year upon land so rich that the crops grown upon it cannot consume a fair proportion of the food supplied.

According to Lawes and Gilbert it has been found, as a matter of practical experience, upon the highly cultivated grain and stock farms of England, that the amount of mineral constituents immediately available for the wheat-crop supplied by stable-manure is almost invariably in excess of the supply of nitrogen. Hence the yield of wheat is largely increased on those English lands by the application of nitrogenous manures used in conjunction with the dung, as has already been set forth.

In a similar sense, Rauch, in Bavaria, after having experimented with Peruvian guano for years, came to the conclusion that he could not count with any certainty upon this manure's giving good results unless it was applied to land already in good heart, i. e. land previously enriched with stable-manure or with clover-sod. The facts being as they are, it is not in the least surprising that the use of a purely nitrogenized manure, like sulphate of ammonia, should have so often given excellent results upon land which had been richly manured for a long time with dung.

It is to be remembered, also, that in many situations — where land is very fertile, either naturally or from having been brought into good condition by careful tillage and abundant manurings, — the annual disintegration and decomposition of mineral matter within the soil will go far to supply the mineral constituents which are taken off in the crops, and that these ash-ingredients are of course superadded to those in the dung. Hence it follows, that the special theory of applying commercial fertilizers, to which allusion was just now made, must be modified very decidedly. In many situations, it will be best to use some kind of nitrogenized fertilizer together with the farmyard-manure. And if this be done, less stable-manure should be applied than is now commonly used. It would evidently be unwise, as a matter of farm practice, to persist in applying large quantities of dung to really good land. A lighter dressing of the dung together with some nitrate of soda, or guano, or fish-scrap, or sulphate of ammonia, would usually be better than a heavy dressing of the dung alone.

The Risk of Losing Nitrogen.

One reason why it may often be better policy to manure the land moderately for each crop, rather than to apply a heavy dressing of dung to one crop in a rotation and none to succeeding crops, is that the organic matter in farmyard-manure slowly but constantly changes in the soil, with formation of nitrates, some portions of which, as is well known, are carried away, during long-continued rainy weather, by the water that percolates through the soil; and since the amount of nitrogen lost in this way is larger in proportion as larger amounts of dung have been applied to the land all at once, the simplest rules of prudence would seem to indicate the propriety of exhibiting the dung in moderate doses and reinforcing it if need be with nitrates after the season of leaching rains has passed. It may sometimes happen nevertheless that land heavily dressed with farmyard-manure may gain such power to hold water that only a small proportion of the rain which soaks into it at the surface can pass out below as drainage.

The recognition by the British farmers of the facts, — 1st, that full crops of wheat cannot be grown unless there be present a liberal supply of nitrogen, as well as an abundance of the mineral matters necessary for the crop, — and, 2d, that upon land which has been highly cultivated for a long time and manured with dung the supply of mineral constituents available for the wheat-crop is usually in excess of the available nitrogen, — mark a very important step in the history of agriculture. It is curious to note how, in the light of this knowledge, some of the difficulties which beset the earlier observers are made plain. Thus, to take a single example, Marshall, writing in 1781, was very much exercised concerning a hill of "manure-sick" land which he ran across in his travels. Under date of November 10, he says: —

> "The Bullock Hill at St. Faith's in Norfolk is said to receive no benefit from the droppings of the bullocks, which every year are shown upon it daily during a fortnight or three weeks in late September and early October. This year the land was in wheat; and if one may judge from the stubble, the crop was a very indifferent one, notwithstanding the wheat was dunged for. The soil is a lightish sandy loam."
>
> "This interesting fact is said to be due to the worthlessness of the dung of drove bullocks. This I much doubt, however; for the bullocks being many of them in high case, and kept in grazing-grounds about St. Faith's, some of them perhaps within a quarter of a mile of the hill, the driving is little more than the driving of sheep to a fold. Some of the cattle may no doubt come to the hill immediately from Scotland, and they are all of them of course driven more or less, and there may be some truth in this opinion. But upon the whole, it seems probable that driving alone does not produce this interesting fact. May we not venture to think it possible that land may be satiated, or tired, even of the dung of cattle? The hill in question has been the site of a large fair for cattle during time immemorial. Perhaps, were the fair removed and the soil manured with lime,

marl, or some such other new manure as experience would point out, it might continue to throw out great crops for many years. This is a subject worth investigating; for upon old grazing-grounds, which have been fed and dunged with cattle during a length of time, the dung which falls from them cannot on this hypothesis be of any use to the land; consequently the stock may, without injury to the pasture, be driven off in the night-time to fertilize some arable land; or the dung may with advantage be collected and carried off; whilst by mould, ashes, soot, etc., the grass may receive improvement."

It will be noticed that Marshall describes the soil of the hill as a lightish, sandy loam. The inference seems plain, that the nitrogen-compounds of the dung had fermented and been oxidized, and that they had been washed away in good part, doubtless in the form of nitrates; and that what the land really needed was a supply of some nitrogenized manure, and, probably, water.

From what is known of the power of soils to retain the mineral constituents of dung, it is impossible to escape the conviction that the soil of this Bullock Hill was highly charged with them. With his usual sagacity, Marshall saw that a new manure was needed. But he did not know that the substance specially indicated was a nitrogen-compound, although he mentions soot and vegetable-mould, among other things, as fit materials to experiment with. His countrymen have learned the lesson since then.

CHAPTER XXII.

SUPERIORITY OF DUNG AND URINE.

Folding and Teathing.

THE foreign practice of applying manure by folding sheep methodically night after night upon the different parts of a field is deserving of special attention in connection with what has been said of methods of saving and applying manure. For, as has appeared already, the sheepfold is one means of bringing manure to the land in the fresh condition, and, in places where circumstances permit this method to be practised, it is esteemed to be a very good way of so doing.

Almost every crop and every kind of soil is said to take kindly to the system, excepting only such clays and silts as would be puddled by the trampling of the animals. In England, folding is highly esteemed on dry loams and especially on chalks, gravels and sands; and the process is reputed to be singularly beneficial to new land, and to land which has never been folded upon. It must be admitted, however, with Marshall, that, "by the term fold, as applied to the fertilizing effect of sheep pent upon land, we do not mean to convey an idea merely of the fæces and urine they leave behind them, but also of the trampling, and perhaps of the perspiration and the warmth communicated to the soil by the practice of folding."

It is not merely the tramping of the ground in the sense of compaction, but the trampling in of the dung, i. e. the mixing of it with the earth, that is to be regarded with favor. It is a matter of history, indeed, that before harrows were invented sheep and swine were habitually employed to trample in seed-grain after it had been strewn. The even distribution of the sheep-manure is one point to be noted; and another advantage in putting sheep upon stubble-fields is found in the fact that these animals eat and destroy a great variety of weeds which neither cows nor horses will touch.

Still, the chief advantage of folding is found in the fact that all the manure falls upon the land in the fresh condition, and is absorbed by, and distributed in, the soil while fresh. This remark is specially true of the urine, which is put to profit, wellnigh completely perhaps, when it falls upon the soil, as when sheep are folded; but which in the barnyard putrefies and ferments in such wise that no inconsiderable part of it is lost. In full accord with these statements is the opinion of practical men that folded sheep give a powerful, quick-acting manure of no great endurance. The chief effect of it will be felt in the first year.

It is true of sheep-manure that it is particularly dry and a highly nitrogenized material, which begins to decompose very quickly anyway, and, by thus becoming hot, helps not a little towards its further decomposition and destruction. No kind of manure (unless it be night-soil) stands in greater need of having checks put upon its tendency to decomposition. On contrasting Voelcker's analyses of fresh sheep-manure with some that was three years old, it appears that the latter had lost more than 40 % of its nitrogen, and somewhat over 60 % of its organic matter.

Folding saves Urine.

When urine has been distributed in the soil in the fresh condition, as when sheep are folded, it probably decays in a very different way, even in warm summer weather, from that in which it decays in the dung-heap, and the products of decay, being in presence of an excess of soil, are doubtless absorbed by it in some part. In case, for example, ammonia was formed by the decay of the sheep's urine in the soil, it is fair to assume that little or none of this ammonia could escape into the air. It is certain that no perceptible odor of ammonia would arise from it, such as is evident enough when sheep's urine decays above ground.

As Walz has suggested, the constituents of urine that have been distributed upon stubble land by the method of folding sheep are commonly put to use immediately by plants, before they have had time to undergo any very complete decay ; for they are either taken up by weeds that are growing upon the spot, and are subsequently recovered in the form of a green manuring when the land is ploughed, or some kind of an agricultural crop is sown upon the land that has been folded upon, and in this event the constituents of the urine give an excellent start to the young plants.

In proof that the urine of the sheep is really the most important element in the process of folding, Walz adduces the case where, after sheep have been folded upon a hillside, a sudden heavy shower of rain washes everything movable from the surface of the land, so that the dung is swept away wellnigh completely, and little beside the urine that had soaked into the earth is left to show that folding has occurred. Yet it is a matter of practical experience, that the crops which are grown in due course upon folded land which has been washed clean in this way, often yield almost as good harvests as if no washing had occurred. Another bit of evidence tending to show the efficacy of the urine is that the straw of grain-crops manured by folded sheep is apt to be particularly well developed, as compared with that of crops grown with farmyard-manure.

One advantage in folding sheep is, that there is no expense directly chargeable to the transportation of manure, or to the spreading of it. Moreover, none of the manure can by any possibility be lost between the stable and the field. In a word, there is no "shrinkage." Hence the process has special significance for outlying fields which are distant from the dung-yard, and for hilly or inaccessible places. Folding is said to be inadmissible, however, when the sheep are kept for the sake of high-grade wool, and land should not be folded upon when it is wet, lest it should be puddled by the feet of the animals.

Sometimes the sheep are folded on land before the crop is planted, in which event their dung is soon ploughed in; and at other times they are folded after the planting, so that their dung serves as a top-dressing, and their tramping harrows and "rolls" the land, as it were. In both cases, the sheep are usually driven at nightfall from their proper pasture to the land to be manured.

In certain parts of England, it has been the practice of some farmers to have their turnip-crops eaten off the land by other persons' sheep at so much the score. In this way, the risk of investing capital in sheep is avoided, though there is a liability that the tilth of the fields may be injured by the trampling of the alien sheep at unseasonable times. As was said just now, this practice was esteemed so highly that, in times when turnips have been specially abundant, a neighbor's sheep have occasionally been permitted to eat the crop without payment; sometimes even money has been paid to induce their owner to permit them to eat.

Quantity of Manure from Folds.

In some German works on agriculture, there will be found curious computations as to the amount of land which one sheep will manure in a night, and as to the value of this manuring as compared with that of a dressing of stable-manure. Schnee estimates that a good medium manuring, equal to about 100 cwt. of ordinary stable-manure, may be got from 2,400 sheep, and that a heavy manuring, equal to about 125 cwt. of stable-manure, may be got from 3,000 sheep. Koppe tells, as a matter of experience, that the folding of 3,000 sheep for one night upon 1 Morgen (= 0.631 acre) of poor, thin land, will give a more luxuriant grain-crop than four wagon-loads of ordinary stable-manure, although 3,000 sheep, with their bedding, will not produce this much manure in a night. Hence the cost of folding is offset by the cost of moving the straw and the manure, to say nothing of the waste of straw, which might be used as fodder. According to Gasparin, a sheep weighing no more than 17 kilos. will yield in one night 0.0037 kilo. of nitrogen to a square metre of land, or 0.022 kilo. for each 100 kilos. of live weight. That is to say, a flock of a thousand sheep will in a single night put nearly 4 kilos. of nitrogen on 1,000 square metres of land, which would be equal to a dressing of 925 kilos. of farm-yard-manure.

One rule was, that the field would get a good dressing of dung from one night's folding when 6 square feet of land were allowed to each sheep, and a medium dressing if 7 feet were allowed to a sheep. Ten square feet to a sheep was the utmost to be allowed, lest the land should be manured unevenly, for sheep huddle together closely when the nights are cool. Another way of reckoning was that, while the sheep-fold would give the land a heavy manuring in one full night, half a manuring could be got by moving the fold to a new place in the middle of the night. As an experiment, Boussingault folded 200 sheep for a fortnight on rye stubble, in a field of such extent that there should be one sheep to four square feet of surface. The crop of turnips grown on the land thus fertilized was as large as those obtained after the heaviest dressings of farmyard-manure.

"*Cow-penning.*"

In several of the Southern States of this country, the poorer classes have long been accustomed to fertilize their land by penning cows upon it methodically night after night during the summer months, i. e. from March to November. This system, which has the merit of absolute simplicity, is said to prevail generally on the high-lying pine-lands of the Cotton States. The pens are nothing more than plots of ground enclosed by a simple rail-fence. The land within the pen is usually ploughed at the start, and to this enclosure the cows — which are allowed to run at large in the woods by day — return at night to suckle their calves, and to be milked.

As soon as the land has become well covered with the droppings of the animals, it is customary to take down the fence, to build a new pen with the rails, to plough the enriched land, and to plant sweet potatoes upon it, or (in Florida) to establish a garden. In case any vegetables are to be grown which require a richer soil than the sweet potato does, the land of the old pen may be ploughed and the cows be penned again upon the newly-ploughed ground. In this way, the land may be enriched so thoroughly that good crops can be grown upon it for years. It has been said that no grove of fruit-trees is more healthy or prolific than one which has been set out on cow-penned land. "Where a man owns 20 head of cattle, or more, it is surprising how much poor land will be transformed into rich land in the course of a single season."

In spite of the fact that it has often been held up to ridicule, this practice of cow-penning is manifestly by no means destitute of merit. Scientifically considered, it is an interesting example of the value of fresh manure.

Manure from Pastured Cattle.

The droppings of neat cattle at pasture have in general far less economic value than those of sheep, not only because of their compacted condition, which prevents the growth of grass wherever they have fallen, but because of the rankness of the grass which grows around them. In rich pastures, or even perhaps in ordinary pastures which are not too rocky or brush-grown, the droppings may be utilized more or less completely, as is done not infrequently in England, by going over the land occasionally with a flexible chain-harrow, — or perhaps a light smoothing-harrow would answer, — so that the clots of dung may be broken up and the particles distributed.

If a scytheman or a mowing-machine could be spared occasionally to cut down the rank tufts of grass which grow around the clots of dung and where an excess of urine has fallen, it would be well also; for cattle will eat such grass after it has wilted, just as they will eat buttercups, whiteweed, and weeds in general, after they have been mown and are partially dried, and they will graze subsequently on the new growth of grass. It can hardly be open to doubt, that, in pastures good enough and smooth enough to suggest the operation, the cost of running a mowing-machine over the land as often as weeds or waste grass have made head would be amply repaid by the forage that is gained. It is true of many weeds that the acrid juices which repel animals from the living plants seem to escape by volatilization as the plants become dry. It is said that even thistles growing in pastures will be readily eaten by all kinds of stock if mown when they are young and succulent.

Quantity of Manure produced in Pastures.

Schnee estimates that the excrements from a medium-sized cow at pasture amount in twenty-four hours to from 37 to 40 lb., or in 165 days and nights to from 6,000 to 6,600 lb. More excrement is passed by day than by night, that which falls by day amounting to from 22 to 25 lb. Hence, when cattle are pastured by day and kept up by night, the pasture will receive from 3,600 to 4,000 lb. of manure in 165 days.

These figures are sufficient to give a tolerably good idea of how much a pasture can profit from the droppings of the cattle kept upon it. Furthermore, they go to show why it is that European farmers think so much more of the benefit derivable from pastured stock than our own farmers do.

On those European farms where a cow can be pastured on less than an acre of land, 4,000 lb. of droppings — say half a cord of absolutely fresh dung and urine — may do an appreciable amount of good to that acre. But with us, where several or even many acres of pasture are needed for the support of a single animal, the manure she furnishes is scattered so widely that no one can see that it has done much good.

Teathe.

The old English writers on agriculture, following a provincial custom, often laid stress on the good effects of the mere breath of cattle upon pasture grass, and upon the benefit which accrues to the grass from the contact of their bodies with it as they sleep by night, — all this beside the effect attributable to the dropping of dung and urine. The word Teathe was used to express this complex idea.

Just as the word "fold" was used to express the fertilizing action of sheep, so "teathe" was used to indicate the fertilizing effect of cattle upon the land upon which they were pastured, or upon which they were foddered with turnips or other food; no matter whether this fertilizing effect is produced by their dung and urine, or by their treading, their breath, their perspiration, or the warmth of their bodies.

A field may be teathed methodically, much as it would be folded. And upon the stock-turnip-grain farms of Norfolk County in England, at the beginning of this century, the practice was wellnigh universal.

Cattle were fatted upon turnips in the field, but the turnips were fed out in such manner that the droppings of the cattle were distributed over the entire field. The farms were laid out, and the crops intermixed, in such manner that each field of turnips should have at least two grain- or clover-fields in its neighborhood. The turnips were hauled first to the wheat stubble, and there scattered thinly and evenly from the carts, so that the cattle, while eating one turnip, could not tread or dung upon another. The carts began at one side of the field, and worked regularly, day by day, to the other side, giving each part of the land an equal share of the turnips, and never throwing twice in the same place, until the whole field had been gone over. The rule was to keep the turnips about a yard apart.

When the wheat stubble had been gone over often enough to give it a proper supply of manure, the ground was ploughed, and the cattle transferred to barley stubbles. The latter were ploughed in their turn, and from Christmas to April the turnips were thrown upon the clover-fields.

This practice of teathing was esteemed to be specially valuable upon light soils, but inapplicable to heavy land or to soils of close texture, — manifestly because of the risk of puddling and tamping the clayey soil.

The teathe of cattle was a merchantable article, like their dung, and it was estimated at a higher or lower price according to the quality of the food and the condition of the cattle. The teathe of heavy, fat cattle was thought to be specially valuable, while that of lean stock and of cows was accounted inferior.

In some localities it was customary to divide the turnips between neat cattle and sheep by partially stripping the fields before the sheep were put upon them. That is to say, from one-half to two-thirds of the roots were pulled and carried off the land, to be given to cattle, and sheep were then turned in to eat the remaining turnips, where they grew. By proceeding in this way a greater breadth of land could be subjected to the beneficial influences of the trampling and droppings of the sheep.

Teathing with Hay.

This matter of teathing applies, of course, much more particularly to the mild climate of England than to the conditions which obtain in the Northern United States. The process is described here merely for the sake of an illustration. It was the mild climate, again, which permitted the farmers to teathe their mowing-fields by foddering cattle upon them in winter with hay, as an equivalent for the exhaustion by hay. In some districts the hay was carried from the stack on men's backs, care being taken to scatter it regularly and to throw it upon fresh ground every day in order that the hay might be eaten up clean, and that all parts of the field should be equally well manured.

According to Marshall, the good effect of feeding out hay upon grass-land that will bear the treading of stock in winter is evident to common observation. There can be no doubt, he says, that in some cases, and under proper management, stacking hay in the field, and foddering with it on the land it grew upon, may be perfectly eligible. On light land, he says, many advantages arise from this practice. The fodder is laid up and the manure applied at small expense. The texture of the soil is improved, and the moss, which is the greatest enemy of land of this description, is checked or destroyed by the treading of the stock.

Nothing of this sort could be done in the cold winters of New England. But it is none the less plain that the custom of teathing goes to show the advantages of using fresh dung and urine. A few words more bearing upon the subject of teathe may here be cited. The famous old writer on rural affairs, Evelyn, says: "The biting of cattle gives a gentle loosening to the roots of the herbage, and makes it grow fine and sweet, and their very breath and treading, as well as soil, and the comfort of their warm bodies, is wholesome and marvellously cherishing." And Hunter, in a note to Evelyn's statement, remarks: "Nice farmers consider the lying of a beast upon the ground, for one night only, as a sufficient teathe for the year. The breath of graminivorous quadrupeds does certainly enrich the roots of grass, — a circumstance worthy of the attention of the philosophical farmer."

Whimsical as these notions now seem to us, it must be admitted that there is no inherent improbability in them. It is a familiar observation, that many varieties of weeds, such as the plantain, mallows, may-weed, and certain grasses, follow the foot of man everywhere. There are probably other plants which frequent the haunts of cattle, and some of them may afford good pasturage. On the other hand, the pressure of the bodies of cattle may be sure death to many undesirable plants.

Teathing with Swine.

An instance of teathing land with hogs on the large scale at a cheese factory in Canada was described in the "Country Gentleman" a few years since. This factory used the milk of 500 cows, and the whey was fed to 100 or 200 hogs. The hogs were kept in a ten-acre lot, preferably of grass-land, or land foul with thistles, and the whey was hauled to the field in tanks, from which it was run out through spouts into long troughs. Once in every two or three days the troughs were dragged into new places by means of horses, so that the field was gone over methodically from one side to the other. In this way the animals were kept healthy; the field was thoroughly manured, and ploughed also by the snouts of the hogs; while the roots of grasses and weeds were pretty thoroughly destroyed. At the end of the summer the land was found to be in excellent condition for winter wheat.

Real Superiority of Dung and Urine.

One important consideration in regard to the action of farmyard-manure, as compared with the action of artificial fertilizers, remains to be discussed more fully than has been done hitherto.

If the question were to be asked, squarely, Why is it that farmyard-manure continues to be so much more highly esteemed by farmers than the commercial fertilizers are? the reply might fairly enough be made, in words that have been used already, First, because farmers and laborers know very well how to manage dung, while they have still a great deal to learn in respect to the use of the chemical fertilizers. Or we might join in the common cry, and say that dung is superior to the chemicals because it is a tolerably "complete" manure. Or it might be urged, as has often been done by writers, that stable-manure exerts a useful physical effect upon the soil, particularly on stiff clays, — an effect such as most artificial fertilizers are incompetent to bring about.[1] To repeat yet again the words of Lawes and Gilbert: "Direct experiments have shown that the soil in our experimental wheat-field, which is manured annually with farmyard-manure, retains near the surface, owing to its greatly increased porosity, very much more of the rainfall than the soil of the plots not so manured. It is, accordingly, found that the drains from the farmyard-manured plot run much less frequently than do those from the unmanured or the artificially manured plots. Hence, obviously, there will be less loss of water by drainage."

Or, finally, it may be argued, very properly, that stable-manure is of the nature of yeast, in that it contains great stores of microscopic organisms which work to ferment the soil and to make the nitrogen in its humus available for crops.

There is much of truth in each of these assertions, as has been urged on previous pages. They do undoubtedly represent several of the great causes which work to maintain the supremacy of dung.

Then, again, it must be remembered that the great bulk of farmyard-manure — no matter how inconvenient and costly this bulk may be as regards the application of the manure — is really of the nature of an advantage, in that it insures a tolerably even distribution of the fertilizing matters, so that every part of the soil becomes charged with them. Hence, as a rule, wherever farmyard-manure is applied in quantities large enough to keep the land in good condition, there is really added to the soil a great store or reservoir of plant-food, both in respect to nitrogenous matters and ash-ingredients. Moreover, farmyard-manure is usually obtained very cheaply, as will be explained in another place.

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[1] See particularly an article by F. Schulze in Poggendorff's Annalen, 1866, 129, 366. Abstract in Hoffmann's Jahresbericht der Agricultur-Chemie, 9, 48.

The Nitrogen in Manure is Superior.

But there is still another reason why farmyard-manure retains its supremacy, and it is, in some respects, the most important reason of all. It depends, to all appearance, upon the peculiar condition of some part of the nitrogen in natural manures.

It will be remembered that, beside nitrates and ammonium salts, plants can feed upon various other nitrogenous compounds, such as urea, uric acid, hippuric acid, guanin, leucin, tyrosin, and the like; beside, doubtless, many other compounds which have not yet been isolated and examined.

It is known that urine and dung, i. e. farmyard-manures, contain a variety of these compounds, and there is every reason to believe that their presence in natural manures is particularly beneficial for the growth of crops in many cases.

As has been set forth in Volume I of the Bulletin of the Bussey Institution, we are forced to admit the presence of some soluble nitrogen compounds other than ammonia or nitrates in farmyard-manure, in order to explain certain familiar facts in respect to the diffusion or soakage of dung-liquors in the soil.

As every farmer knows, the earth of a field may become perfectly saturated with soluble nitrogen compounds to a very considerable depth at the spots where dung-heaps have lain undisturbed for some time. Indeed, the places where dung has lain are often unfitted for the growth of useful plants, other than some rank-growing tropical vegetables, such as water-melons or pumpkins.

Now the nitrogen compounds which thus surcharge the soil are evidently not ammonium salts, for ammonia would be fixed near the surface, and could not sink so far into the earth. Nor are they nitrates, for dung-liquors are seldom rich in this form of nitrogen. For the present, it is known only that they are soluble organic nitrogen compounds, probably of the same order as some of those whose names have just been enumerated. Perhaps there are several different compounds; but, however that may be, the facts go to show that the nitrogenous dung-liquor soaks into the ground with especial ease; that it diffuses itself, within certain limits, in all directions; that it does not decompose very rapidly in cool weather; that plants are particularly fond of it; and that it is not so easily washed out of the land, perhaps, as nitrates are. From all this, it is manifest that, until we can copy this valuable peculiarity of the dungs, our so-called artificial processes of fertilization will labor under one great disadvantage.

The experiments just now alluded to as having been reported in the Bussey Bulletin were as follows. During a couple of years, trials had been made with a variety of fertilizers upon a level field, a part of which had purposely been left bare, in order that it might be used subsequently for another set of experiments. Some of the experiments of the early years required dung, and a place was set apart expressly for the reception and storage of it. But it was found to be impracticable adequately to guard the premises against irresponsible teamsters, and, in fact, several loads of the manure were deposited by mistake upon the fallow land.

Pains were taken immediately to remove this misplaced manure as completely as possible, and the spots where it had been thrown were carefully marked. Finally it was found, when the fallow land came to be planted, in 1873, that rather better crops grew on the places where the dung had fallen than upon the adjacent land, although this last, as well as the dunged land, had received large dressings of mixtures of phosphatic, nitrogenous, and potassic manures. It was plain that the dung had made itself felt, even when in presence of a large excess of the chemical fertilizers.

Thanks to its easy and even diffusion, and perhaps to its being able to supply nitrogen continuously to the plants throughout the season, or to its being able to supply nitrogen in some peculiarly favorable form, or, possibly, to the presence in it of useful micro-organisms, the dung did unquestionably exhibit a kind or form of power which the commercial fertilizers lacked.

Of course, an experiment such as this goes far to justify and support the prejudice of practical farmers, that dung is really a better manure than the plants from which it came. It goes to show withal, and that emphatically, that the ploughing in of a green crop may be a very inferior method of manuring, as compared with the common system of transforming the crop to dung by means of cattle, and then putting the dung upon the land. But if this inferiority be real, a fatal blow is struck at Boussingault's dictum that cattle are dissipators of manure; and we are compelled to accept, with but little reservation, the old and widely-spread prejudice, that there is nothing like dung and urine.

Experiments by Kellner have shown that soils do not fix and hold urea, as they do ammonia; and it is to be remembered, in respect to fresh manure, that urea is by far the most important of the soluble nitrogen compounds, which are contained in it. But it is evident from the foregoing statements, that beside urea, there are other organic nitrogen compounds available, and extremely useful for plants, not only in fresh manure, but also in that which has been thoroughly rotted.

Old Manure Helps Artificials.

Some of the experiments made to test the value of humus bear upon this point, since they clearly illustrate the fertilizing power of the organic nitrogen in manure. Thus Corenwinder obtained the results given in the following table, by growing one beet-plant in a pot of sand watered with a solution of ash-ingredients and nitrates, and another in vegetable mould from a compost-heap, which was practically thoroughly decomposed horse-manure.

	There was harvested from the Sand. Grm.	Compost. Grm.
Leaves	270.00	2,560.00
Roots	490.00	1,145.00
Sugar in 100 grm. of juice	12.26	10.60
Sugar in the root.	60.07	121.37

There are the experiments also of Dehérain, who added the black matter of rotted manure to earth taken from a field which had been cropped for a dozen years without manuring, and had become so much exhausted that beets and clover grown upon it were miserable. There was found in this soil no more than 0.7 % of carbon, in the form of organic matter, instead of 1.6 % as in fields which had been regularly manured. Various artificial fertilizers were added to pots of this earth, in some cases with and in others without admixtures of the black matter of well-rotted manure, and oats and hemp were grown in the pots, as stated in the following table: —

Mixtures in the pots.	Crops harvested. Oats. Grm.	Hemp. Grm.
Good soil, manured in previous years, but not in 1890, the year of the experiment	...	35.8
Exhausted soil, without any addition	19.7	15.5
" " with artificial fertilizers	28.8	22.8
" " " black matter of well-rotted manure	23.5	25.7
" " " black matter and artificials	30.7	38.4

For the hemp in particular the nitrogen of the organic matter did excellent service.

Dehérain urges, as a matter of practical experience, that in seeking to recuperate land which has been exhausted by cropping, artificial fertilizers alone will not suffice.

The significance of the dung-nitrogen as an adjunct to, or re-enforcement of nitrate-nitrogen, is well shown by some experiments made by Dehérain, in France, on a light, slightly calcareous soil, as set forth in the following table. In each of the 4 years, oats did best when dressed with a mixture of manure and nitrate, but, ordinarily, they did better with manure alone than with nitrate alone. It will be noticed that in the favorable season of 1880, a very heavy crop was got from the mixture. There were harvested in the stated years, the given numbers of hectolitres of oat-grain from one hectare of land: —

	1878.	1879.	1880.	1881.
No manure	51.10	27.90	53.70	31.00
Nitrate of soda	54.40	38.40	46.25	29.00
Farm-manure	52.30	52.40	43.80	32.75
Farm-manure and nitrate of soda	56.20	66.30	82.50	55.00

In a subsequent year (1888), Dehérain harvested 84 hectolitres of oats to the hectare of land, from a field which had been dressed lightly with a mixture of farm-manure and nitrate of soda, while 71 hectolitres were got from a field that received no manure. In this year also, he harvested 59 and 60.3 hectolitres of wheat, respectively, to the hectare, from fields which had been dressed with a mixture of farm-manure and nitrate of soda. But he urges that it is upon sugar-beets that the mixture produces the most marked effects. Thus, he obtained kilos. of beet-roots to the hectare of land from

	In 1887.	In 1888.	In 1889.
Nitrate of soda alone	20,700	....	35,600
Sulphate of ammonia alone	17,800	....	....
Farm-manure and nitrate of soda	40,000	40,100	40,050
Sulphate of ammonia and nitrate of soda	....	25,320	....

It may here be said, yet again, that the totality of the nitrogen in farmyard-manure is not nearly so valuable, pound for pound, as that in nitrates and ammonium salts. It is only that comparatively small proportion of the nitrogen in manure which was contained in the urine of the animals that is to be regarded as readily and rapidly available for promoting the growth of plants. Much of the nitrogen in ordinary farmyard-manure was contained in the litter with which the animals were bedded, and in the undigested or partially digested matters which have been discharged in their dung, and there can be little doubt that some part of this nitrogen must be practically valueless, or that the remainder is of varying degrees of inertness or efficiency, while all of the nitrogen in nitrates and ammonium salts is good, and each particle of it as good as any other. Lawes and Gilbert long ago presented evidence of "the much less effect of a given amount of nitrogen supplied in farmyard-manure, than as ammonia salts or nitrates." They found, in fact, that a much larger proportion of the nitrogen in these compounds was recovered in the increase of the crops produced by using them than was recovered in the increase obtained on using farmyard-manure; and they showed, furthermore, that the addition of nitrate-nitrogen to farmyard-manure had a very marked effect on the growth of crops.

Guano similar to Dung.

The question arises immediately, Is there not among all the commercial fertilizers any one, or perhaps some mixture of several, which can be classed with farmyard-manure in respect to this useful diffusibility of nitrogen?

Yes; there is one, and that is the so-called rectified guano, — "unlocked guano," the Germans call it, — i. e. Peruvian guano which has been treated with sulphuric acid. Undoubtedly the original Peruvian guano deserves to be classed in the same category; but, in the experiments here to be cited, the rectified guano approved itself so particularly that it will perhaps be best to dwell upon it rather than upon the unimproved raw material.

In one word then, it may be said that the most dung-like of all the commercial fertilizers is the one best fitted to compete with farmyard-manure. It will be observed that in this fact we have the strongest possible indication of the truth of the dictum, that it is the peculiar nitrogen compounds in farm-manure that give it its special power. Nothing can be more significant of the fact that this nitrogen is really the efficient cause, than the other fact, that, in seeking to compete with the dungs, experimenters have been forced at last, after trying all other kinds of nitrogenized fertilizers, to rest contented with what is really another kind of dung; or, at the least, the experimenters have brought up at a product obtained by the chemical treatment of the bird-dung (guano) with acid.

As is well known, guano contains, beside ammonium salts, a quantity of uric acid, some guanin, and small amounts of various other nitrogenized organic matters, all of which doubtless have a somewhat different action upon vegetation from the ammonium salts. Guano is, in short, one of the most complicated of all known fertilizers.

About half the nitrogen in guano is in the form of ammonium salts, while the other half is in the form of the organic compounds just spoken of; and among these organic compounds uric acid is the most abundant. The true original Peruvian guano, that contained some 12 or 13 % of nitrogen, contained as much as 10 or 15 % of uric acid in combination with ammonia, as has been seen.

The chemical composition and the behavior of uric acid are tolerably well known, and the same may be said of guanin also; but of the other nitrogenized matters which occur in small proportions in guano next to nothing has been ascertained hitherto. Chemists are ignorant as to the composition of these things, and as to their relations to other chemical substances. It is not known in the least how they behave when treated with sulphuric acid, for example.

As for the action of sulphuric acid on uric acid, it may be that some of the uric acid is changed thereby to a more soluble substance, though the supposition is rather improbable. It was urged at one time that some of the uric acid is changed to ammonia when guano is acted upon by sulphuric acid. But Grouven denies this, and says that he finds very little more ammonia in rectified guano than in crude guano.

At first sight, the chances would seem to be that the uric acid in rectified guano must come to the earth as such, — much as would have been the case if the original crude guano had been applied to the land, — and that the only beneficial action of the sulphuric acid treatment is to make the phosphoric acid in the guano soluble. But, as will be seen directly, there is some evidence that works against this supposition. It may be true, after all, that the sulphuric acid does good simply by killing the micro-organisms in the crude guano, and thus hindering the uric acid from fermenting when the guano is mixed with the soil. It is not at all improbable that uric acid can thus be preserved from decomposition for a considerable period of time, and so kept in fit condition to play its own peculiar part for helping the growth of crops. This idea is strengthened by the fact of observation, that guano, when admixed with a germicide substance, such as common salt, often does particularly good service as a fertilizer.

That uric acid is a substance which does not decompose readily is evident from the very fact that so much of it exists in guano, a substance which has long been exposed to air and weather — probably for hundreds of years. Sestini has shown moreover that uric acid may be kept unchanged for months when suspended in water and freely exposed to the air; though both free uric acid and urate of ammonia may readily be decomposed by adding a small quantity of putrid urine to the water, and maintaining it at a temperature of 75° or 80° F. Two kinds of micro-organisms have been detected in putrid urine which act as yeasts to ferment uric acid and urates and change them to carbonic acid and carbonate of ammonia. For the success of this fermentation both air and warmth (as of midsummer) are necessary, and no nitrogen is lost, for all the nitrogen of the original uric acid is found again in the ammonium carbonate and in the new crop of micro-organisms produced.

Superiority of Guano.

The first scientific inkling of the real superiority of guano over artificial mixtures of the so-called chemical fertilizers was got by the German chemist Grouven, who subsequently studied the question in some detail.

In 1862 Grouven had a number of field experiments with fertilizers carried out on the large scale, upon twenty different farms in various parts of Germany. On comparing the results of these experiments, he was struck with the fact that, as a rule, the mixtures of ammonium salts and superphosphates, and of nitrate of soda and superphosphates, which had been employed, failed to answer so good a purpose as rectified guano did in respect to the size of the crops harvested, though it had been proved by analysis, at the start, that the mixed fertilizers contained amounts of nitrogen and of soluble phosphoric acid which were equivalent chemically to those in the rectified guano.

Grouven published some remarks upon this point at the time, and dwelt upon the noteworthy circumstance that the sale of rectified guano was steadily gaining ground in Germany, as it had been for some little time previously, in spite of constant efforts on the part of the manufacturers of fertilizers to compound a mixture artificially which should be equally good with the guano. So long ago as 1872 a large proportion of all the guano imported into Germany was treated with sulphuric acid before it reached the farmers' hands.

In order to be perfectly sure of the facts, as above stated, Grouven repeated his experiments in a very thorough way. He had a number of trials carried out during four years by several different farmers of repute, to whom he furnished fertilizers which had been analyzed after very careful preparation. These fertilizers were designated by numbers merely, so that the actual experimenters — the farmers to whose land they were applied — had no precise knowledge of what they were using, and consequently could not have had any very forcible bias in favor of either one of the mixtures.

The following table of averages, taken from the great mass of Grouven's results, will illustrate the general position of guano in comparison with the positions of other manures. It will be seen that the action of the guano is allied to that of the dungs, and that it is superior to that of the simple superphosphates, nitrates, and ammonium salts : —

INCREASE OF CROP PER HECTARE OVER THE UNDUNGED FIELDS.

(1 centn. beets = ⅕ thaler ; 1 centn. oats = 2 thalers ; 1 centn. straw = ⅖ thaler.)

Manure per Hectare in 1862. (1 centn. = 50 kilos.)	1862 Sugar-Beets. Average of 20 Fields. Thalers.	1863. After effect of Oats and Straw. Average of 13 Fields. Thalers.	1864. the Manures. Beet-Roots. Average of 12 Fields. Thalers.	Cost of the Manures per Hectare, in Thalers.
700 centn. cow-dung . . .	54.4	20.8	35.6	72
700 " horse-dung . .	67.6	30.4	58.0	80
700 " sheep-dung . .	84.4	38.4	55.2	90
6.3 Peruvian guano . . .	50.8	11.6	15.6	30
12.6 " " . . .	71.2	16.4	16.0	60
25.2 " " . . .	95.2	30.8	31.6	120
15.6 superph. à 13 % . . .	35.2	5.2	31.2	34
31.2 " " . . .	42.4	5.2	35.6	68
6.3 sulphate of ammonia	19.6	0.0	0.0	36
12.6 " " .	46.0	4.0	0.0	72
5.9 nitrate of soda . . .	34.8	2.8	0.0	34
11.8 " " . . .	56.8	5.2	0.0	68

All the dungs, fertilizers and seeds came from one and the same source. The sowing and harvesting were done on the same days, and the plan of all the experiments was the same.

Of course it would be natural, in so far as this table alone goes, to explain a good part of the differences by falling back upon the fact that guano, like the dungs, is a tolerably complete manure, while the superphosphates and the nitrogen compounds are special manures, and altogether one-sided; but, as will be shown directly, this explanation is wholly insufficient.

As confirming Grouven's results, the following table, drawn up by Stoeckhardt, may be cited. It was published in 1862 as a compilation from all the field experiments on sugar-beets that had been reported during several preceding years: —

Peruvian guano gave better crops than nitrate of soda in	11	out of	22	experiments.
Better than ammonium salts in	9	"	10	"
Better than bone-meal in	25	"	40	"
Better than superphosphate in	23	"	32	"
Better than rape-cake in	20	"	28	"
Better than cow- and farmyard-manure in	14	"	17	"
Better than horse-manure in	6	"	12	"
Better than urine or barnyard-liquor in	13	"	18	"

These results, as well as those obtained by Grouven, are tolerably emphatic. But at the time of these trials, as Grouven reports, the reproach was constantly made that the use of guano alone must be injudicious. It was urged that the guano contained too much nitrogen in proportion to its other ingredients; that it was consequently one-sided, and must inevitably tend to exhaust the land. It was argued that it is too uncertain, especially in dry years, and too costly. The advice was repeated upon every hand, that guano had better be used in conjunction with other cheaper fertilizers, such as the superphosphates, bone-meal, and potash-salts, or even with ammonia-salts, or with nitrate of soda, so that no more than half the cost of manuring a field should be spent upon guano.

Additions to Guano.

Among other receipts, the following were often recommended, viz., half guano and half potash salts; also one-third guano, one-third potash-salts, and one-third superphosphate; so, too, mixtures of guano and sulphate of ammonia, and of guano and nitrate of soda, were recommended as powerful forcing manures; and it had been claimed at one time or another, for all of these mixtures, that they were surer and more profitable than guano alone.

Grouven proceeded to put some of these suggestions to the test of experiment. Like most, if not all, agricultural chemists, he had believed *a priori* that many such partial substitutions as the foregoing would really be more rational than the use of guano alone. It is probable that his real purpose in trying the mixtures was to find which among them was the most efficient.

He tried mixtures in which one-third or one-half of the guano had been replaced by two other fertilizers of equal cost with the guano that had been removed. His results were as follows: —

Year.	No. of Fields of from 1 to 1½ Hectares.	No. of Comparisons with Guano.	No. of Resu'ts that were favorable for the Guano.
1861	10	20	18
1862	24	72	46
1863	13	39	31
1864	12	36	21
1865	8	40	27
1866	13	91	39
1868	11	44	27
1869	16	16	7
1871	7	28	22
1872	3	3	2
Sum	117	389	240 = 62%

That is to say, of 389 experimental plots on 117 different fields, there were 240 results favorable to the use of simple guano. There were only 38 results in a hundred where the guano alone yielded smaller crops than the mixtures of guano and other fertilizers.

Of course this result applies to rich German lands, and doubtless to soils which were more evenly and abundantly supplied with moisture than most New England soils are, for example. There is nothing in the results to dissuade us Americans from using potash-salts with guano, or from using guano in small quantities as an addition to other manures. But as an illustration of the peculiar attribute of guano now under discussion, the results are not a little remarkable. It may be said, indeed, that the table really means more than Grouven claimed for it, since it shows so well the peculiar efficacy of the nitrogenous matters in guano when added to good strong land, such as the best fields of Germany are. The soil of the fields where these experiments were tried was naturally rich and strong. It needed an excitant rather than a mixture of fertilizers; and the results given in the tables show that guano and the dungs afforded the necessary nitrogenous excitation.

Crude Guano Inferior to Rectified.

Next in order came experiments in which plain guano and rectified guano were contrasted. The following table relates to sugar-beets. Each plot got 47 thalers' worth of fertilizer. The crops are the means obtained from thirteen different fields, each one hectare in area: —

1866.	Unmanured.	360 Centn. Best Stable-Manure.	10 Centn. Crude Peruvian Guano.	10 Centn. Rectified Guano.
Excess of crop (washed roots) over the unmanured . . .	. . .	46.0 centn.	85.0 centn.	103.0 centn.
Per cent of sugar in the juice	13.7	13.5	13.6	14.1
Degrees marked by Brix's hydrometer	16.4	16.3	16.8	16.6
Other matters beside sugar in the juice, per mille . . .	27.0	28.0	32.0	26.0
Increase of sugar over the unmanured	. . .	6.2 centn.	11.5 centn.	14.5 centn.

Here is a marked increase of crop in favor of the rectified guano, as compared with the crude; and the result was true, not merely for the average of all the cases, but for the greater number of cases as well. And it is remarkable that the rectified guano was so much better than the crude, in spite of the fact that the 1,100 lb. of crude guano which were used to the hectare (440 lb. to the acre) contained one-fifth more nitrogen and one-fifth more phosphoric acid than were contained in the same weight of the rectified guano.

The rectified guano crops gave a much purer juice withal. They contained more sugar and less saline matter than the others. But a pure juice like this is a great gain for the sugar-maker, since in the absence of salts and other impurities the sugar crystallizes out more readily and more completely. Sugar makers prefer not to have either stable-manure or artificial fertilizers applied directly to their beets. They would like to have the crop grown after wheat, or other grain, which had been manured. But in the experiments above cited, even the undunged fields, which are commonly held to yield the purest sap, gave results which were inferior in this respect to the fields that had been dressed with the rectified guano.

This result is remarkable from the scientific point of view, and may perhaps lead eventually to a clearer understanding of how and why it is that plants take in the unnecessary salts. Grouven remarks, that, while no fertilizer or mixture of fertilizers known to him has in general so beneficial an effect upon the quality of beet-juice as rectified guano, no such effect can be attributed to crude guano. On the contrary, the tendency of crude guano is, if anything, to injure the quality of beet-juice. From this fact, Grouven draws the inference that the action of sulphuric acid upon guano must be in reality more emphatic than any one would have been disposed to believe *a priori*. He argues, that no mere change, such as the fixing of the ammonia in the guano, or the rendering of its phosphoric acid soluble, can be supposed to produce a physiological effect upon the beet-root so striking as this alteration of the juice. But, as was suggested before, it is not impossible that the sulphuric acid, by destroying ferment germs in the crude guano, may hinder its uric acid from changing either to ammonium carbonate or to nitrates, and so permit the uric acid to feed crops in its own peculiar way during a considerable part of their terms of growth.

"*Guano Substitutes.*"

Grouven next proceeded to contrast rectified guano with certain so-called substitutes for it that had been thrown upon the German market in large quantity. One of these guano substitutes was a mechanical mixture of 50 lb. of sulphate of ammonia, with about 9½ lb. of nitrogen, and 50 lb. of Baker Island superphosphate, with about 9½ lb. of soluble phosphoric acid; while another (less common) was 62 lb. of nitrate of soda, with about 9½ lb. of nitrogen, and 50 lb. of Baker Island superphosphate, with 9½ lb. of phosphoric acid.

Of the first of these mixtures 100 lb., and of the second 112 lb., were very nearly chemically equivalent to 100 lb. of the rectified guano with which they had to compete.

It will be noticed that Grouven leaves the potash in the guano entirely out of the account, which is unfortunate for the New Englander, since he cannot escape the conviction that it must have had a certain amount of beneficial action. It is to be remembered, however, that many, if not most, of the rich German soils contain an abundance of potash, and that there was a mass of farm experience to justify Grouven and the makers of fertilizers in neglecting potash. In the experiments where crude guano and rectified guano were contrasted, there was of course more potash in the crude than in the rectified material.

As for the guano substitutes just spoken of, the cost of either of them was very nearly the same as the cost of rectified guano, at the time when Grouven made his experiments.

CENTNERS OF POTATOES PER 1 HECTARE, MEANS OF 11 HARVESTS FOR 1867.

360 Centn. Stable Manure.	7.1 Centn. Nitrate of Soda + 5.6 Centn. Superphosphate.	5.6 Centn. Sulph. Ammonia + 5.6 Centn. Superphosphate.	10 Centn. Rectified Guano.
331	374	373	381

Since the average yield of the unmanured plots was 303 centners of potatoes, it appeared that the increase was 28, 71, 70, and 78 centners, respectively. Moreover, the potatoes from the rectified guano fields were somewhat richer in starch than those from the other fields.

CENTNERS OF POTATOES PER 1 HECTARE, MEANS OF 15 HARVESTS FOR 1869.

	No Manure.	5.3 Centn. Sulph. Ammonia + 5.3 Centn. Superphosphate.	7 Centn. Nitrate Soda + 5.3 Centn. Superphosphate.	470 Centn. Stable-Manure.	10 Centn. Rectified Peruvian Guano.
Mean total harvest .	304	349	353	364	369
Mean increase . .	...	45	49	60	65

MEANS OF 7 HARVESTS FOR 1871.

	No Manure.	360 Centn. Stable-Manure.	3.1 Centn. Sulph. Ammonia + 7.3 Centn. Superph.	3.5 Centn. Nitrate Soda + 7.3 Centn. Superph.	7 Centn. Rectified Guano.
Total . .	227	248	252	262	282
Increase .	...	21	25	35	55

FOR 1872.

Trial No.	No Manure. Centn. Potatoes.	4.9 Centn. Sulph. Ammonia + 5.3 Centn. Superph.	9.4 Centn. Rectified Guano.
1	84	141	181
2	235	323	332
3	289	430	380

Grouven very justly remarks that the reader must not be deceived by the absolute smallness of the numbers as here cited. Since the figures are the means of many experiments, — some of which were of no account either way, and some of which gave results that were contrary to the majority of the results, — they can hardly fail to be small. But they nevertheless represent the real superiority of the rectified guano. Moreover, it is a fact that, out of 36 different fields, the rectified guano gave decidedly better results in 24 instances than its ammoniacal competitors. That is to say, the guano gained the day in two out of every three of the trials. So too, out of 33 fields where the rectified guano was put in competition with mixtures of nitrate of soda and a superphosphate, the guano excelled in 22 instances, or two times out of three, again.

Taking the whole 46 cases (24 + 22) where the guano gave the best results, it appeared that the average excess of crop due to the guano, over and above what was yielded by the substitute, was 3,322 lb. of potatoes per hectare. But, on the other hand, in the 23 instances (12 + 11) where the substitutes for guano gave the best crops, it appeared that the gain over the guano was no more than 2,684 lb. of potatoes per hectare. Or, to sum up, the rectified guano was better than the proposed substitutes in two-thirds of all the trials, and produced on the average some 1,300 and odd pounds of potatoes more per acre than the equally costly substitutes.

Guano on Grain.

It might be said, indeed, by some persons, that, although the foregoing statements may be true enough as regards potatoes, they might not hold true for grain. But the burden of proof would lie upon whoever was bold enough to make such a suggestion as this; for it is well known that guano is an excellent application for grain, and that the more thoroughly a manure can diffuse itself into all parts of the soil, so much the better will the grain-crop be suited; and, as Grouven urges, it is precisely this power of rapid and useful diffusion which makes the rectified guano a better fertilizer than the substitutes. The objection would, moreover, have been refuted by the fact that by far the larger part of the rectified guano sold in Germany at that time was used upon grain-crops.

Grouven cites the following experiments as illustrating this fact of useful diffusion. Two loamy fields, that had not been manured for five years, were divided into plots of 1,900 square feet. Barley was grown upon one of these fields one year, and the year after wheat was grown upon the other. The results were as follows: —

1857.	The Manure contained		Harvest.	
1st Field. — Barley.	of Nitrogen. lb.	of soluble Phosph. Acid. lb.	Grain. lb.	Straw. lb.
No manure	...	...	13.6	36.7
13.4 lb. phosphate of ammonia	2.8	7.2	14.6	36.0
20 lb. guano	2.8	2.6	34.4	66.6
1858. 2d Field. — Wheat.				
No manure	...	...	36.2	65.9
11.9 lb. phosphate of ammonia	2.5	6.4	43.0	77.9
18.8 lb. guano	2.5	2.4	65.9	158.0

The upshot of the matter is, clearly, that the nitrogenized constituents of the guano do better service than the nitrogen of the ammonia compounds and the nitrates; or, rather, that they do a certain kind of service which the ammonia salts and the nitrates are unable to perform.

Both the ammonium salts and the nitrates are well enough as far as they go, and it may perhaps be true that the ammonia salts in guano do as much good as either of the other nitrogenous constituents which the guano contains, or even more. But there is evidently some substance in guano, and in animal excrements in general, which helps and reinforces the ammonium salts.

Not all the Nitrogen in Dung is Perfect.

As was just now urged, it is well understood as a matter of course, that only a comparatively small part of the nitrogen in ordinary farmyard-manure, and especially in manure which is well rotted, can be in the active, easily assimilable condition so much insisted upon in the foregoing paragraphs. It is perfectly well known in fact that a large proportion of the nitrogen in farm-manure is not immediately available for crops, and there is good reason to believe that much of it first becomes fit food for plants when subjected to the process of nitrification. But it is none the less true that a considerable part of the nitrogen in dung and urine exists in peculiarly valuable forms, and the inference is not far to seek that specially useful results may be gained in many cases by applying moderate dressings of fresh manure in conjunction with appropriate mixtures of artificial fertilizers.

It is true that, taking one year with another, Lawes and Gilbert were able to grow as large crops of wheat and of barley by means of mixed artificial fertilizers as with dung. But the question of paramount interest is, how to use together mixtures of dung and artificials, in order to get the best economic results. During 32 consecutive years Lawes and Gilbert applied farmyard-manure, to one plot of wheat-land at the rate of 14 long tons — estimated to contain 200 lb. of nitrogen — per year and per acre, while to another plot they applied a mixture of mineral fertilizers and 86 lb. of nitrogen, in the form of ammonium salts. The averages of the amounts of dressed grain and of total produce (grain and straw) obtained per year and per acre are given in the following table: —

Averages of	Farm-Manure.		Artificials.	
	Grain, Bush.	Total, lb.	Grain, Bush.	Total, lb.
8 years, 1852–59	34.4	6100	35.5	6490
8 years, 1860–67	35.8	5926	36.3	6262
8 years, 1868–75	35.3	5932	31.0	5379
8 years, 1876–83	28.6	4798	28.0	5248
32 years, 1852–83	33.5	5689	32.8	5845
40 years	32.4	5516	. . .	. .

In these experiments, it was calculated that there was carried to the soil in the farmyard-manure more than twice the amount of nitrogen supplied by the artificial fertilizers; and it was observed furthermore in the two years 1863, '64, that the total produce obtained from land which had received 400 lb. of dung-nitrogen amounted to 13,653 lb.; while other land, which received 144 lb. of ammonia-nitrogen, gave crops that weighed 20,043 lb., or more than 6,000 lb. excess of crop in the two years. In one word, so much of the dung-nitrogen is in inert forms that large applications of it were needed in order to grow the same amount of crop as was produced by comparatively small quantities of nitrogen in the form of ammonium salts.

Farmyard-Manure on Green Crops.

Since wheat and barley cannot bear heavy dressings of dung, other kinds of crops should naturally be looked to in considering the merits of dung. Thus, Dehérain grew fodder corn (maize) during five successive years on light land with the result, as stated in the table, that farmyard-manure gave better crops than mixed fertilizers: —

Kind of Fertiliser.	Kilos of Green Crop to the Hectare. Mean of 5 Years.	Last Year.
No manure	47.160	22.500
Farmyard-manure	79.960	76.500
Nitrate of soda and superphosphate	67.210	33.400
Sulphate of ammonia and superphosphate	52.370	33.000

With potatoes, the results were as follows: —

Kind of Fertiliser.	Hectolitres to the Hectare. Mean of 5 Years.
No manure	244
Farmyard-manure	303
Nitrate of soda and superphosphate	286
Sulphate of ammonia and superphosphate	278

Guano with Sulphates.

Some experiments may here be cited in which mixtures of guano and gypsum, or guano and Epsom salt, gave good results when contrasted with mere guano. These results may perhaps eventually help to explain the superiority of rectified guano, although their full meaning cannot as yet be seen. Krocker made experiments on oats and on wheat, as follows: —

Oats on a Clay Soil.

On a Morgen (= 0.631 Acre) of Land.	Crop. Grain.	Straw and Chaff.
1 cwt. of guano	420	2,880
1 cwt. of guano treated with 5 lb. of sulphuric acid	440	3,000
1 cwt. of guano and 1 cwt. of gypsum	560	3,340

OATS ON SANDY LOAM.

On a Morgen (= 0.631 Acre) of Land.	Crop. Grain.	Straw and Chaff.
1 cwt. of guano	608	2,332
1 cwt. of guano and 5 lb. of sulphuric acid	646	2,643
1 cwt. of guano and 1 cwt. of gypsum	773	2,645
WHEAT ON A CLAY SOIL.		
1 cwt. of guano	815	2,030
1 cwt. of guano and 5 lb. of sulphuric acid	880	2,310
1 cwt. of guano and 1 cwt. of gypsum	970	2,370

These results go to show that the good effect of the rectified guano cannot depend solely on the existence in it of soluble phosphoric acid. Moreover, it can hardly be true that the action of the gypsum to set free potash from the double silicates in the soil is the sole cause of the increase of the crops, for some gypsum was, of course, formed by the addition of sulphuric acid to the guano, as stated in the second line of each division of the table.

Hellriegel urged that sulphate of magnesia mixed with guano would decompose its ammonium salts, with formation of nonvolatile sulphate of ammonia, which is less subject to decomposition than the urate and oxalate. Experiments on winter rye that were made at his suggestion gave the following results: —

	Grain.	Straw and Chaff.
No manure	448	1,328
1 cwt. guano	544	1,688
1 cwt. guano and 10 % sulphate of magnesia	572	1,656

In another locality the results were as follows: —

1 cwt. guano	356	1,294
1 cwt. guano and 10 % sulphate of magnesia	447	1,627

The Merit of Dung-Nitrogen should be recognized.

Although it is not yet known precisely how or when the organic nitrogen compounds in dung or guano do their work in the soil, the fact of such ignorance should not deter any one in the least, either from recognizing that a peculiar kind of work is done, or from allowing for it as a practical force.

The chances are, that the merit of the dung- or guano-nitrogen depends not only on its being evenly distributed in the soil, but also upon the fact that by means of it fit kinds of food are supplied to the plant successively, continuously and by instalments. As has been said, ammonium salts are liable to be fixed by the soil too near the surface, and to be changed more or less speedily to nitrates and to inert humus; while the nitrates tend to be washed out of the soil altogether.

Guano (and Dung) a very intimate Mixture.

Another thing to be said is, that artificial mixtures of fertilizers can never be made so intimate as the guanos and dungs are naturally. The smallest kernel of guano, like all the other kernels, large or small, contains, namely, a great variety of fertilizing matters. But when a mixture of an ammonium salt and a superphosphate is scattered abroad, or when the two substances are applied to the land one after the other, there will inevitably be left great gaps and interspaces between the unlike particles when they fall upon the ground. To meet this difficulty some German manufacturers of fertilizers have dissolved a quantity of sulphate of ammonia in the sulphuric acid which they use for making superphosphates. The idea is that when this acid is made to act upon a powdered rock phosphate it can hardly fail to commingle the ammonium salt with every particle of the phosphatic manure.

The futility of trying to copy guano precisely has been urged by Voelcker in the following terms. Take the case of milk, he says: we know the composition of milk far better than we know the composition of guano. But the best mixture we can make of casein, sugar, butter, ash-ingredients, and water, all in the proper proportions, can hardly be called milk, and no one would expect such artificial milk to produce precisely the same physiological effect as real milk. And so it is, he goes on to say, with our substitutes for guano.

The old Humus Theory an Expression of the real Merit of Dung.

It was probably from observing the great, and, as is now known, the peculiar, fertilizing power of barnyard-liquor, — which they not unnaturally regarded as a solution of humus, — that the older agriculturists were led to attach an exaggerated importance to humus, considered as a kind of plant-food. Indeed, the so-called humus theory, which for many years was a prominent article of faith among agricultural writers, probably depended in good part on this observation, and on the palpable fertilizing power of well-rotted dung. When, for example, Hlubeck said "the extract from rotten organic remains forms the proper nourishment of plants, and is the more efficacious in proportion as it has come from a variety of animal and vegetable substances," it seems plain that he must have been thinking of the drainings of dung-heaps. So too the favor in which thoroughly rotted dung was held probably depended in part on its looking like humus; while, conversely, much of the credit so long accorded to humus may justly be attributed to its looking like rotted dung. The habitual use by New Englanders of the word "muck" as a synonym of bog-earth is manifestly an expression of this idea.

Few Commercial Fertilizers diffuse readily.

One of the limitations to which most commercial fertilizers are subject was clearly indicated at the Bussey Institution on seeking to recuperate with chemicals a field of rather poor land, after a variety of experiments had been made upon it during a term of years with special fertilizers. It then appeared that it was no easy matter to mix some of the artificial fertilizers properly with the soil.

Excepting superphosphate of lime and nitrate of soda, the fertilizers appeared to be fixed for the most part where they fell upon the exhausted land; and it seemed as if the subsequent crops had to struggle with streaks and seams of poor soil interspersed with streaks of soil that were over-rich in respect to one or another kind of fertilizing agent. These results went to show that the ploughing-in of green crops may have real merit as a means of refreshing worn-out soils, considered merely as a means of distributing the fertilizing matters, or rather of putting them where they will do the most good, and of bringing land into condition by making it fit for ferment organisms to live in.

Dung still needed.

Some years ago, the following computation was published by Lawes, for the sake of bringing clearly into view the importance of rotating crops and of growing green crops for feeding cattle, in order to produce manure; and with the view of showing how inadequate the artificial fertilizers then procurable were for producing such large quantities of grain as were grown in Europe. It will be noticed that the calculation relates to a single English county of no great size.

> "The county of Norfolk is said to comprise 1,338,880 acres of land: suppose one-half of this to be cultivated on the four-course system, 334,720 acres will be under corn every year. It will not be considered an exaggeration to say that cultivation in this county has increased the natural produce of grain by 10 bushels per acre, and according to my calculations it would require something like 50 lb. of ammonia to be supplied in any artificial manure to produce this increase of grain; and considering one ton of Peruvian guano to contain 224 lb. of ammonia, it would require an importation of 74,714 tons to supply the necessary amount for one year."

CHAPTER XXIII.

NIGHT-SOIL.

As has been set forth already, there can be no doubt that fresh human excrements are richer in fertilizing matters than those of farm animals. The food of man is commonly much more concentrated than that of animals. It is richer in respect to nitrogen and phosphates, and, as analysis shows, the excrements derived from such food are correspondingly concentrated and valuable. Contrasted analyses of various dungs and urines have already been given in Chapter XIX., and a just idea of the merit of human excrement may readily be gained by comparing its composition with the figures of those tables. According to Wolff, the average composition of human excrements is as follows: —

	Water.	Organic Matter.	Nitrogen.	Phosph. Acid.	Potash.	Lime.	Magnesia.
	%	%	%	%	%	%	%
Fresh human fæces .	77.2	19.8	1.0	1.10	0.25	0.62	0.36
Fresh human urine .	96.3	2.4	0.6	0.17	0.20	0.02	0.02
Mixture of the two .	93.5	5.1	0.7	0.26	0.21	0.09	0.06
Mixture of the two in Japan (Kellner) .	95.0	3.4	0.57	0.13	0.27	0.02	0.05

As ordinarily procurable, night-soil is far from containing so large a proportion of fertilizing matters as fresh excrement, because of the fermentations and leachings to which it is usually subjected, and because of its liability to be mixed with water and with other diluents, such as coal-ashes and rubbish. Indeed, one strong objection to the use of night-soil, as obtained at random from a town or city, is its great liability to variation. The farmer can seldom be sure as to the real value of any given load of it, — not nearly so sure as he would be in the case of horse-manure or cow-dung. As has been already intimated, many farmers near Boston are willing enough to use night-soil provided they can obtain it in the form of fresh solid excrement, and a similar practice was noted long ago by Kuhlmann in the North of France, who remarked that practical men recognize the fact that those samples of unadulterated night-soil which contain the largest proportion of solid matter (dung) have a more lasting fertilizing effect than samples which are more liquid, though in case the liquid part of night-soil was once really urine, and not extraneous water, it will act more quickly as an active nitrogenous manure than the solid excrement could, and is consequently as valuable for certain purposes as the actual dung.

Some conceptions as to the average composition of fairly good night-soil, as taken from vaults not subject to leaching or dilution, may be got from the following table of analyses.

ANALYSES OF NIGHT-SOIL (MOSTLY LIQUID) FROM VAULTS.

	Water. %	Organic Matter. %	Nitrogen. %	Phosph. Acid. %	Potash. %	Lime. %	Magnesia. %	Chlorine. %	Soda. %	Specific Gravity.
Quesnoy (near Lille ?), Girardin (not diluted)*	98.04	2.66	0.92	0.33	0.21	....	....	....	....	....
Ditto, from a large factory, much diluted with water*	99.65	0.05	0.18	0.03	0.02	....	....	....	....	....
Lille, from a dwelling-house, diluted with 12 to 15% water* . .	99.86	0.54	0.67	0.10	0.15	....	....	....	....	....
Paris, L'Hôte†	99.12	1.28	0.44	0.14	....	0.16	....	....	....	....
Munich, mostly liquid .	95.51	2.01	0.18	0.26	....	....	....	....	....	....
" thick liquid .	90.52	7.35	0.69	0.52	....	....	....	....	....	....
Karlsruhe, from a large public collecting vault (Nessler)	96.00	3.00	0.40	0.12	0.17	....	....	....	....	....
Ditto, 1864	....	....	0.41	0.19	0.14	....	....	....	....	....
Ditto, " (filtered) . .	....	....	0.33	0.02	0.09	....	....	....	....	....
Ditto, 1866	....	....	0.35	0.06	0.19	....	....	....	....	....
Ditto, 1883	....	....	0.30	0.05	0.15	....	....	0.30	0.25	0.013
Ditto, " (thinner) . .	....	....	0.18	0.03	0.08	....	....	....	....	0.008
Ditto, " " . .	....	....	0.15	0.03	0.08	....	....	....	....	0.008
Ditto, 1886	....	....	0.28	0.04	0.07	....	....	0.24	0.31	0.010
Ditto, "	....	....	0.25	0.03	0.05	....	....	....	....	0.012
Ditto, "	....	....	0.29	0.04	0.05	....	....	0.27	0.24	0.011
Cassel, public vault into which tubs from private houses were emptied (Nessler) . . .	....	....	0.8-1.0	....	....	....	....	....	....	....
Freiburg, from a public collecting vault (Nessler), 1888	....	....	0.34	0.06	0.12	....	....	0.24	0.18	0.013
Ditto, 1888, from the vault of a private house . .	....	....	0.52	0.14	0.18	....	....	0.31	0.26	0.026
Nessler's average of many analyses . . .	....	....	0.31	0.06	0.11	....	....	0.27	0.25	0.013
Stuttgart, from a public collecting vault (Wolff)	94 to 98	1.51	0.43‡	0.15-0.19	0.18-0.21		....	....	....	....
Stuttgart, thicker . .	96.40	....	0.54	0.20	0.27	....	....	....	....	....
Amsterdam (A. Mayer)	81.5	9.3	0.56	0.69	0.13	....	....	....	....	....
Amsterdam, from barrels (A. Mayer) . . .	85.0	12.7	0.94	0.54	0.37	....	....	....	....	....

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* The first specimen contained 0.76% of ammonia; the second, 0.21%; the third, 0.57%; all with traces of nitrates.

† This specimen contained 0.52% of ammonia. The average of 12 different samples was 0.37% of nitrogen, the amount having ranged from 0.25 to 0.62%.

‡ 0.37% as ammonia and 0.06% as organic nitrogen.

Amsterdam, from Liernur's * receptacles (A. Mayer)	97.7	1.6	0.24	0.04	0.12	....	....	....	....	....
Groningen, average, mostly liquid (Fleischer)	97.10	....	0.29	0.01	0.36	....	....	....	....	....
Bremen, average, solid and liquid (Fleischer)	31.70	....	0.52	0.51	0.26	2.71	....	....	....	....
Riga (Thoms) † . . .	94.48	4.34	0.41	0.12	0.20	....	....	....	....	....
Average composition of night-soil from cities, mostly liquid (Wolff)	95.50	3.00	0.35	0.28	0.20	0.10	0.06	....	....	....
Japan,‡ complete mixture of fresh solid and liquid excrement as carried out from Tokio to the farm-land . .	95.31	3.18	0.59	0.13	0.29	0.02	0.05	....	....	....
Japan, night-soil from houses of middle class inhabitants of Tokio .	94.51	3.89	0.57	0.15	0.24	0.02	0.06	....	....	....
Japan, night-soil from soldiers and sailors .	94.41	4.07	0.80	0.30	0.21	0.03	0.05	....	....	....
Japan, mixture of fæces and urine from peasants living on farms near Tokio.	95.29	3.03	0.55	0.12	0.30	0.01	0.03	....	....	...

Samples of fermented night-soil from Lille, such as is used in Flanders, gave Boussingault and Payen 0.19 % and 0.22 % of nitrogen. One hectolitre (26.4 imperial gallons) of this material weighed 275 lb.

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* In the method devised by Liernur, the soil-pipes from the closets of a considerable number of houses are connected with a central receiver sunk in the public street. This receiver is a tight iron vessel of spherical shape and of about 20 C. F. capacity. At each house there is a valve accessible from the street, by means of which the closet can be shut off from the receiver. The receiver is emptied every night, or as often as may be desired, into an iron tank which, together with a steam-engine, is set upon wheels and drawn about by horses. The tank is put in connection with the receiver by means of an iron pipe, the house-valves are closed, and an air-pump is set in action by the steam engine to remove the air from the receiver. The several house-valves are then opened and closed one after the other, and the matter which has collected in the traps of the soil-pipes is instantly shot over into the receiver by the downward pressure of the air in the soil-pipes. In the same way, the contents of the receiver are subsequently forced into the exhausted tank, which is then hauled away to receive the contents of the next receptacle. The foul air pumped out from the receivers and from the tank is blown into the fire of the engine-furnace.

The plan was to use a minimum amount of water; to avoid the putrefaction of the fæcal matter; to empty the pits without any offence to the householders; and to deliver their contents to the farmers in a fresh condition. Fatal objections to the process are the first cost of the apparatus and the small value of the manure, which is really a good deal diluted, as the analysis above given shows. Mayer says that at a time when farmers were paying considerable sums for the best night-soil from ordinary vaults at Amsterdam, there was no outgo for the matter removed from the Liernur receptacles in that city. It had to be thrown into the sea.

† Ammonia Nitrogen, 0.36. Organic Nitrogen, 0.05.

‡ These analyses of Tokio night-soil are specially interesting, because of the peculiar food of the Japanese, which consists largely of vegetable matter, much of which has been salted. The farmers, especially, even those living close to the cities, eat little or nothing else. The soldiers and sailors, on the contrary, get a moderate amount of flesh; and in consonance with this diet, their excrements more nearly resemble those of Europeans. The analyses are by Kellner and Mori.

According to L'Hote, a litre of the liquid part of night-soil, from which the solid matters have settled out, weighs on the average 1,023 grm., and contains 991.20 grm. water, 12.80 grm. of nitrogenous organic matter, 5.24 grm. of actual ammonia, 1.35 grm. of phosphoric acid, 1.59 grm. of lime, and 0.79 grm. of silica and sand.

In some parts of the world, notably in China, Japan, and Belgium, where much low-lying land devoted wholly to agriculture is situated within easy access of crowded towns and cities, human excrements are highly esteemed and largely used as a fertilizer. But it is noteworthy that little or no repugnance is there felt with regard to the storing, transportation, and manipulation of the material; and it is certain that some of the processes customary in those countries would not be tolerated in countries more keenly alive to considerations of decency, comfort, and health.

It is true withal of most regions where farming is practised, that night-soil is not an available resource, for very little of it is ever produced upon any one farm. Moreover, with the exception of China and Japan, — countries, that is to say, where very few animals are kept, — stable-manure is produced in abundance in cities, and is always preferred to night-soil by the neighboring farmers.

Repugnance of English-speaking Races to Night-soil.

In England and America, most persons, farm laborers included, have been led to regard the manipulation of night-soil as loathsome and degrading drudgery, to be avoided whenever possible. There can be no doubt, however, that this sentiment dates from a time when the night-soil had to be dipped out by hand-labor from vaults in which the material had passed into a most offensive condition of putrefaction. But now that mechanical appliances have been invented for emptying the vaults in cities, and for transporting their contents in such manner that no odors are perceptible, and that ways and means of controlling the odors at the farm have come to be more generally understood, there is less reason than there was formerly for objecting to the use of night-soil.

There can be no question, by the way, that the old repugnance was justifiable and praiseworthy when not carried to extremes. That the feeling marked a certain progress in refinement, and in civilization even, can hardly be gainsaid. All practices which tend to destroy the self-respect of the persons that engage in them are manifestly out of place in civilized communities. From the accounts of travellers in China, it is evident how exceedingly offensive the manipulation of night-soil may become whenever the agricultural belief in its efficacy is generally diffused in a given locality, and is permitted to override other considerations.

Undoubtedly the repugnance of the English-speaking races to have any dealings with night-soil is one prominent reason why this substance has played so small a part in the development of English and American agriculture. But it is not the only reason, for, as was just now said, the contents of cesspools that have been left for some time to themselves undergo fermentations of such character that the matter loses a very considerable part of its value. Much of the nitrogen, especially, is apt to fly off, and leave the residual substance so much the poorer; and, as has been said, old night-soil is liable to be rather poor stuff any way.

Night-soil is a Forcing Manure.

Moreover, night-soil is a less complete manure than the strawy products ordinarily obtained in the farmyard. It is ill-fitted for use by itself alone, and in the best farming practice it has always been employed in conjunction with other kinds of manure, as a nitrogenous re-enforcement. Indeed, night-soil was strongly objected to formerly by many uninstructed farmers because of its forcing character and supposed tendency to exhaust the land. This difficulty could readily be met nowadays by using appropriate artificial potassic and phosphatic fertilizers in conjunction with the night-soil. Phosphates are especially needed, as Kellner has urged, when night-soil is employed for growing grain, or other seed-bearing crops. Some farmers near Boston have found their advantage in using night-soil together with strawy horse-manure; for the two kinds of manure supplement each other in some part as regards chemical composition, and the odor of the horse-dung masks that of the night-soil.

Isolated attempts have been made occasionally in Europe to carry on farms of mixed cultivation, with no other manure than night-soil, but in the course of a few years the grain-crops became very light as to grain, and ran almost wholly to leaf. It has long been generally recognized that if night-soil were to be used by itself for growing grain, it would be necessary to apply it to the land several months before sowing. Unless this precaution were taken the plants would be apt to run to leaf so strongly that they would be extremely liable to lodge. In case it were used to top-dress grain in the spring, and the season should turn out to be wet, the crop would be forced to such an extent, and would grow so rank that it would probably amount to nothing. It can hardly be insisted too strongly that it is as a re-enforcement to other manures on good moist land, and for garden vegetables and those forage crops which are benefited by abundant supplies of active nitrogen, that night-soil is specially useful.

According to Kuhlmann, writing in 1840, at Lille, in the north of France, where 100 gallons of fermented night-soil were regarded as being very nearly equivalent to 2,000 lb. of half-rotted stable-manure, the usual method of employing night-soil in his vicinity was in conjunction with stable-manure, for the production of rape-seed, wheat and oats. In the first year of the rotation, the land was covered with ordinary long (half-rotted) stable manure in October or November, and the manure was ploughed under. Some 6,000 gallons to the acre of fermented night-soil were then spread upon the land and ploughed under. After this preparation, rape-seed was sown. In the autumn of the 2d year, some 1,200 to 1,600 gallons to the acre of the night-soil were ploughed under before seeding the land to wheat; and in the 3d year, 1,200 gallons to the acre of night-soil were applied and ploughed under before seeding with oats in the autumn.

In case the land should happen to be too soft to permit the hauling on of the night-soil in the autumn just before seeding to grain, it was sometimes applied as a top-dressing in the following March, though it was always a difficult matter to distribute it on seeded land without unduly injuring the crops, for the land was apt to be much cut up by the carts and horses. When thus spread in the spring, one-fifth less of the manure was applied than would have been used in the autumn.

A good example of the forcing (nitrogenous) action of night-soil was seen in the old European experience that this manure is unsuitable for fields where clover is to be sown together with spring grain, for even when the grain was sown very thinly on land manured with night-soil, its straw grew so thick and strong that the young clover-plants were apt to be smothered by it. In the vicinity of Boston, it is a popular opinion that night-soil is unsuitable for potatoes, because they are apt to run to tops when dressed with it, and not to form many tubers; there are European experiments also which confirm this view.

Schmid, in Austria, sowed barley on several plots of 0.58 hectare, and shortly after seeding he applied to one of them 60 metre-centners of an excellent night-soil compost made from fresh excrements and crumbly peat, while to another he applied 60 kilos. of nitrate of soda. Both the crops were strong and vigorous, and they were equally good. They were vastly better than barley grown on unmanured land. In the following year, the crops on the land which had been manured with the night-soil were excellent, while those on the nitrated land were no better than those grown on unmanured plots. Similar results were obtained in experiments made with wheat and with oats.

Undue Praise of Night-soil.

It is a curious fact that, in spite of the unwillingness of Englishmen and Americans to handle night-soil, many people in both countries entertain highly exaggerated views with regard to the money value of it. Formerly it was much the fashion also to attach undue values to poudrette and other products prepared from night-soil. Far too much stress used to be laid withal upon the fact that there were formerly several cities in Europe — notably, Strassburg, Mannheim, Lyons, Antwerp, Ostend, and several other Belgian towns, in regions given over to the old Flemish system of using liquid manures — that received considerable sums of money from contractors who removed the night-soil and sold it as manure, instead of having to pay out money in order that the night-soil should be removed. This matter turns of course upon the estimation in which night-soil is held by the farmers in the immediate vicinity of the city, and there is a wide diversity of opinion in different localities.

In most cities of Continental Europe, however, the removal of night-soil and sewage is a bill of expense, as it is in England and America. Taking the whole civilized world into consideration, less and less use is made of human excrements every year, and the cost of getting rid of the filth of cities tends continually to increase. At Boston, it must be admitted that night-soil is a very cheap source of nitrogenous manure for those farmers who care to use it. Market-gardeners, in particular, so situated that they can readily dilute the material with water and apply the diluted liquid to crops, would probably find their advantage in building special reservoirs for its reception.

As has been said already, it is in regions devoted to gardens, where forcing manures are needed for leafy plants, that night-soil has been most highly esteemed. Indeed, the facts that night-soil is used so largely in China and Japan, and is used so little in Europe, are manifestly correlated with the custom of Europeans to subsist upon grain, while the inhabitants of the far East depend chiefly upon vegetables for their support.

Sanitary Considerations take Precedence.

In reality, the price which a city may obtain for night-soil is not a question to be seriously considered. The fact that a city expends no money for removing night-soil, or that it gains money by the sale of it, cannot for a moment justify the maintaining of vaults and other abominations in its midst. From the point of view of the citizen, it is in terms of health and of comfort that the problem must be considered, and not in terms of money. It matters not what the night-soil of a city may be worth, so long as sanitary considerations require that the offensive material should be immediately diluted with such an enormous bulk of water or earth that the recovery or utilization of the fertilizing ingredients would cost more labor or carriage than they are worth.

Estimated Value of Excrements.

Several chemists have computed how much plant-food is contained, on the average, in the solid and liquid excrements of a man in a day and in a year. The following table, from Heiden, which is based on a large number of analyses, refers to the average inhabitant of a European city, excluding children less than five years old. The weights in the columns headed "Year" are pounds avoirdupois.

	In Solid Form.		In Liquid Form.		Total.	
Amount produced.	Day. grm.	Year. lb.	Day. grm.	Year. lb.	Day. grm.	Year. lb.
Excrement	133.0	107.0	1,200.0	964.0	1,333.0	1,071.0
Dry matter . . .	30.0	24.4	64.0	51.4	94.0	75.8
Organic matter . .	25.5	21.8	50.0	40.2	75.5	62.0
Nitrogen	2.1	1.7	12.1	9.7	14.2	11.4
Ashes	4.5	3.9	14.0	11.0	18.5	14.9
Phosphoric acid . .	1.4	1.1	1.8	1.5	3.2	2.6
Potash	0.6	0.5	2.3	1.9	2.9	2.4

Allowing that the nitrogen is worth 18 cents the pound, and the phosphoric acid and potash 5 cents the pound each, the yearly value of the excrement of a single person would be $2.25, supposing it were possible to put the excrements to immediate use. On multiplying this sum by hundreds of thousands or a million of inhabitants, or even by several millions, as has been done again and again in the case of London, figures are obtained of very considerable magnitude; and many persons have been led to believe at one time or another that some part of these calculated values might actually be realized. Numerous, and in several instances thoroughly well-considered efforts, have been made to accomplish this result; but, with some trifling and limited exceptions, such schemes have invariably failed.

As will be seen from the table, so large a proportion of the weight of human excrements consist of inert and worthless matters, to begin with, that, at the very best, night-soil cannot possibly bear the cost of transportation, even for moderate distances; and, as will be shown directly, it is no easy matter, economically speaking, to recover any part of the valuable constituents from a material which contains so small a proportion of them, and which is so offensive to manipulate.

Much Water in Night-Soil.

The large proportion of water naturally contained in human excrements is of itself an enormous obstacle to their use in agriculture. As has been stated already, analysis shows that the water in fresh fæces amounts, on the average, to more than 75 %, while in urine there is usually some 95 or 96 % of water, so that, even if there were no such thing as water-closets, and if appliances were devised to prevent rain-water and house-slops from mixing with night-soil, and for keeping the latter fresh and for transporting it without offence, it would still be true that the proportion of useful ingredients in the mass of water and other useless matters that chiefly constitute night-soil is too small to admit of the general use of this kind of manure. Until some cheap and easy method shall be discovered of depriving the excrements of their moisture, the use of them must inevitably be restricted to the immediate neighborhood of the spot where they are produced.

Some years ago, an English engineer named Bridges Adams proposed to introduce into London, instead of water-closets, a mechanical arrangement by means of which urine and fæces should be collected apart, so that the urine might be barrelled up and sent by rail into the country. Mr. Adams argued that profit could be derived from such commerce in urine, of which, as he calculated, 24,428 tons could be collected annually in London. But, as was shown at the time by Dugald Campbell, the conception was founded on ignorance. Since, on the average, no more nitrogen could be counted upon in the urine than would be equivalent to 0.7 % of ammonia, it would be necessary to use about 30 tons of urine in order to apply 0.5 cwt. of ammonia to an acre of land. The cost of transporting 30 tons of liquid 20 miles out of London would at that time have amounted to about $10, while half a hundred-weight of ammonia could have been bought for less money than that, either in the form of sulphate of ammonia or of guano, and the cost of applying either of these substances would be vastly less than the cost of applying the urine.

Although the prices of ammonium salts and of guano have changed materially since Mr. Campbell made this computation, his conclusion is still true. It would withal still be difficult to keep the closets clean and odorless, and to prevent the urine from putrefying during the transportation.

Easier to extract Ammonia from Urine than to transport the Latter.

Technically speaking, it could hardly be advisable to try to transport so bulky an article as urine, in view of the fact that the nitrogen in it might be extracted in the form of ammonia, by way of distillation, and the phosphoric acid by methods of precipitation; although, as has already been shown, it may perhaps be true that the urea in fresh urine is really more valuable as plant-food than the ammonia into which the urea changes when urine ferments.

Methods of moving Night-soil.

In regions where large quantities of human excrements are employed in agriculture, as in China and Japan, and indeed in some of the smaller European cities, the materials are collected in jars, or buckets, or barrels, and carried out to the farm land in a tolerably fresh condition. According to Kuhlmann, the night-soil hauled out from cities to the farms in Belgium and the North of France is run into great underground cisterns, of from 50,000 to 80,000 gallons' capacity, and there kept in store. In order to be fit for use, the contents of a cistern should have fermented during several months, and in order to ensure this fermentation, it is customary never to empty a cistern completely, but to add from time to time new quantities of fresh night-soil to replace whatever may have been taken out. During the fermentation, the manure becomes less liquid and more viscid than it was originally. There is no harm in leaving the manure in the cisterns as long as convenience may dictate. Even after three years, the contents of a cistern have been found not to have depreciated in quality to any appreciable extent. In case the night-soil at a farmer's disposal happens to be too watery, it is sometimes re-enforced by throwing into the cistern a quantity of powdered rape-cake, and this material is also sometimes mixed with good night-soil when not enough of the latter can be obtained to fully manure the fields.

In Japan, on the other hand, it is said to be customary to dilute the fresh night-soil with 2 or 3 times its volume of water in wooden tubs where it is allowed to ferment for a week or so in warm weather, or for ten days in spring or autumn, until a green scum, due to the growth of fungi, has formed upon the surface of the mixture. Kellner and Mori have observed that during this fermentation much carbonate of ammonia is formed, and that care is taken to avoid losing it.

Tubs instead of Cesspools.

Several convenient arrangements for facilitating the transportation of night-soil have been devised, such, for example, as small barrels permanently fastened to handbarrows, or a barrel hung between the wheels of a handcart; or tubs are used that are provided with handles or ears, through the slots in which poles can be thrust, so that two men can readily lift and move the tub even when it contains a considerable weight of material. Such tubs or barrels, when tightly covered, can be moved without offence. They commend themselves in the country in cases where many persons are congregated at any one place, and where there is not enough water at hand for the proper supply of water-closets.

When properly managed, movable tubs or barrels are preferable on several accounts to vaults or cesspools, such as were ordinarily employed before the introduction of water-closets. These vaults were simply sunken cisterns of wood or brickwork, in which the excrements were allowed to collect until there was occasion to empty the vault. Usually they were emptied or partially emptied once a year, or sometimes even less frequently. From being left so long undisturbed, some part of the contents of the cesspool were constantly in a state of putrescence. Offensive gases were continually exhaled from these receptacles, and, even when tightly built at first, they were ultimately liable both to leak and to overflow, and so to poison the neighboring ground and the water of wells which was derived from that ground.

One advantage to be credited to the primitive system of tubs and barrels is, that, unlike cesspools, any leakage or overflow from them would be quickly detected, and easily remedied before the ground in their vicinity had had time to become surcharged with the foul liquid.

Methods of utilizing Night-soil.

Allusion has already been made, under the head of Composts, to the mixing of night-soil with peat and loam, both for the sake of absorbing the liquid and the odoriferous portions of the material, and for exciting the fermentation of humus. Indeed, an ordinary method of dealing with night-soil is either to bring it directly to land that is to be ploughed, or to compost it in the fields with earth, and valuable manure may be had in this way, especially in case the night-soil should happen to be fresh; and particularly in localities where canals permit the material to be cheaply and easily transported.

One objection to the long-continued use of uncomposted night-soil on plough-land is said to be that it tends to make land hard and compact. Mr. J. J. H. Gregory, of Marblehead, after using night-soil during 12 to 15 years, found that "the ground baked so hard that it wore out the best tools pretty fast." It is not impossible that this difficulty may be due solely to the muddiness of night-soil. A large part of the night-soil obtainable in American cities may be described as thick mud-puddle liquor which does not dry readily, is not easily absorbed by peat or straw, and has little if any disposition to settle. Mechanically considered, it is a magma of puddled earth and papier-maché, well calculated to stop up the pores of almost any soil, and to destroy its tilth. By receiving the muddy liquor in shallow basins in the field, and throwing upon each load of it a covering of horse-manure, weeds, peat, and coal-ashes, the muddiness may be corrected and the material made more convenient for use. There was formerly a farm near Paris to which night-soil was brought in bulk in boats, whence it was pumped into pipes that carried it to the fields. It was applied, by way of irrigation, in conjunction with water from the canal, much dilution being needed when night-soil is applied to growing crops.

Even under the most favorable conditions, as when the irrigation could be practised during or immediately after rain, ordinary thick, muddy night-soil was mixed with 5 or 6 times its bulk of water; while urine, or the liquid part of night-soil, was diluted with 3 or 4 parts of water. In times of drought the materials were used in a state of much greater dilution. A field of potatoes irrigated for the sake of the experiment, at a very dry time in June, with the undiluted liquid portion of night-soil, suffered extremely. "The plants were burnt up, and after a few days their leaves and small branches fell off. New shoots sprang up from below, new tubers were formed and the older ones died away. The two succeeding crops of wheat and oats, however, profited largely from this misapplied dressing. Even on beets, the undiluted liquor did not produce a favorable effect in a hot season. . . . Night-soil alone, applied to crops in full growth during hot weather in summer, is always more or less injurious." (Moll.)

Belgian experience teaches that a highly effective method of using night-soil is to mix it with from 3 to 6 times its bulk of water and to apply this mixture in the spring to young plants. The diluted liquor does good service in summer also when applied during rain. As was just now said, it has long been customary in Belgium for the farmers to keep night-soil in special cisterns, where it can be admixed with water, and sometimes with rape-cake also or other re-enforcement. From these cisterns the dilute putrid liquid is hauled to the fields in casks from which it is run out little by little into movable troughs, whence it is thrown upon the land by means of long-handled scoops. So too in Japan, according to Kellner, experience has taught the farmers not to apply fresh human excrements to their crops. It is said to be customary in that country to mix the excrements with 2 or 3 times as much water, and to leave this mixture for some time in tubs in order that it may undergo decomposition. The material is held to be fit for use when a greenish color has appeared upon it.

While admitting fully the well-known fact that fresh urine, or night-soil, may do no little harm to plants, unless they have been largely diluted with water, Kellner insists that neither fresh nor decomposed human excrements contain anything which is directly poisonous to plants. He attributes the injurious effects which are sometimes observed wholly to undue concentration of the manure. The crops are injured because their roots come into contact with a great excess of soluble matters. Even the presence in the soil of too strong a solution of urea may interfere so seriously with the absorption of water by the roots of plants that their leaves will wilt.

Peat Poudrette.

In some European cities attempts have been made to prepare merchantable manure from night-soil by mixing with it peat, peat charcoal, charcoal-dust, or tanbark, in quantities large enough to solidify the mass. But the products thus prepared have had very little real value, considered as commercial manures. They are still too bulky and too heavy to bear the cost of distant transportation. The following table contains the results of analyses of mixtures of peat and night-soil as prepared in various cities of Northern Europe:—

	Water.	Organic Matter.	Ash-Ingredients.	Nitrogen.	Ammonia Nitrogen.	Phosph. Acid.	Potash.
Braunschweig (Schultze)	83.10	14.60	2.30	0.78	....	0.22	0.28
Munster (Koenig) . . .	87.45	10.13	2.42	0.55	....	0.44	0.17
Bielefeld (Koenig) . .	83.82	10.47	5.61	0.36	....	0.51	0.40
Groningen (Fleischer), private house	69.85	....	....	0.84	....	0.32	0.28
Do., public place . . .	86.53	....	....	0.63	....	0.25	0.31
Dresden, silica poudrette (Schroder)	26.6	7.3	58.6*	0.44	....	0.35	....
	4.0	8.0	79.8*	0.46	....	0.35	....
Riga (Thoms) I.	81.90	13.30	4.80	0.65	0.12	0.34	0.21
II.	76.80	18.15	5.05	0.95	0.45	0.68	0.23
III.	82.00	15.72	2.28	0.64	0.35	0.53	0.15

One trouble with these peaty products, and with analogous mixtures, is that much of the nitrogen exhibited by analysis is simply the inert nitrogen that was naturally contained originally in the peat or other diluent.

City "Compost."

In several Dutch and North German cities so-called "composts" are prepared by the municipal authorities by mixing the night-soil with all manner of refuse, such as street-sweepings, ashes, and other kinds of "dry dirt" collected from houses. In this way the muddiness of the liquor is corrected, and the mixture has proved to be extremely useful as a means of improving the condition of newly reclaimed land from which peat has been removed, to be used as fuel. As a practical fact, street-sweepings applied to these peaty soils greatly improve their mechanical condition, and the mixture of sweepings and night-soil produces effects not readily obtained by means of commercial fertilizers. Mr. Jenkins, writing of the reclamation of peat-land in the Netherlands, has said, "Sand and peat will not mix easily together, and it is useless to try to mix them unless large quantities of farmyard-manure are applied. This greatly facilitates the process, but artificial manures have no such effect. . . In reclaiming peat-land, sand is laid on and heavy dressings of street-manure are given, and each succeeding year the land is cultivated to a slightly greater depth."

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* Insoluble in acid.

It is to be said that the "street-composts" of Groningen and other towns have done their most remarkable service on peats of exceptionally loose texture, which have been mixed with sand. After the merchantable peat has been dug out and sold for fuel, the system of cultivation is to put back the loose, mucky, unmerchantable peat, which has been thrown aside as refuse, and to mix it intimately with the sand at the bottom of the excavation, where it originally lay beneath the bed of peat. To this new land the compost is applied, in the Province Groningen, at the rate of 3 or 4 tons to the English acre, as a help to the process of reclamation. The land is then sown with rye, upon which a mixture of clover and grass seeds is sown; and, after the rye has been harvested, the land is pastured during several years in order that it may become firm. Subsequently, rye, peas, potatoes and hay are taken as the usual crops, though under specially favorable conditions rape-seed, horse-beans and wheat are grown. It has been observed that in order to grow oak trees upon such land dressings of street-sweepings seem to be essential.

It is reported that the street-sweepings have great and peculiar merit, as a means of firming the land in the first place. After this purpose has once been accomplished the compost is applied in smaller quantities than those stated above. It will be noticed, however, that the night-soil in the compost must help to ferment the humus of the soil and to change it from an inert to a mellow condition. Stable-manure is said not to be esteemed, at the time when the land is in process of reclamation, because of its loose, non-binding character; and green-manuring is objected to on similar grounds.

These city composts, which appear to be mere mixtures, must necessarily vary in different cities, and in any one city also, according to the different kinds and quantities of materials that are added to the night-soil. In some places, the dry dirt is picked over much more carefully than in others, and the coarser matter is sifted out. It is said that at Amsterdam, 32 different classes of materials, ranging from paper to the different kinds of metals, are separated from house-refuse before the finer part of it is added to the night-soil. Analyses of some of these "composts" are given in the following table: —

		Water.	Organic Matter.	Ash-Ingred.	Nitrogen.	Phosph. Acid.	Potash.	Lime.	Mag.
Brussels (Petermann, July)		4.20	22.89	72.93	0.39	0.60	0.31	3.17	0.74
Brussels (Petermann, Nov.)		7.26	17.74	75.00	0.17	0.44	0.32	3.71	0.39
Bremen (Fleischer)	I.	31.05	....	....	0.57	0.44	0.30	2.68	....
	II.	35.51	....	....	0.47	0.55	0.24	2.70	....
	III.	28.52	....	....	0.53	0.53	0.23	2.76	....
Emden (Fleischer)	I.	55.74	....	....	0.43	0.48	0.42	1.77	....
	II.	27.80	....	....	0.79	0.95	0.66	2.62	....
	III.	55.74	....	....	0.49	0.59	0.40	1.60	....
Groningen (Fleischer), mean of the analyses of 4 years.		63.18	....	....	0.73	0.50	0.24	1.79	....
Cologne (Dietrich) . .		....	....	....	0 24	0.19	0.18	1.48	....
Brünn (Kohlrausch) .		40-43	9-15	46-48	0.5-2.0	0.01-0.84	0 60	....	....
Berlin (Heidepreim) .		....	5.97	....	0.41	1.06	2.33	22.63	1.11

At Treves, on the Moselle, a much more elaborate system than the foregoing has been adopted for converting night-soil into a manageable material, and a really powerful manure is prepared there by mixing street-sweepings, horse-manure, night-soil, peat and chemical fertilizers. Into a tight pit 2 metres deep, 45 metres long, and 10 metres broad, there is thrown a layer of peat about 5 c. m. thick, which is covered with some 10 c. m. of horse-manure, and this, in its turn, with 2 c. m. of fine, sifted street-sweepings. Between each of these layers there is strewn a certain amount of kainit, of phosphatic slag and of phosphatic gypsum. The layers of peat, horse-manure and sweepings are repeated until the total thickness of these absorbents amounts to about 30 c. m., while the uppermost layer is of peat. The pit is then filled to the brim with liquid night-soil, a part of which is immediately absorbed, while some of the mere water flows off into a cistern, whence it can be pumped back into the pit to cool its contents. This last operation is necessary, since the matters in the pit speedily enter into fermentation, and they would become unduly heated if they were not drenched occasionally.

After a time, the contents of the pit are found to be compact and firm; they are cut down and out with sharp hoes and loaded upon railway cars to be hauled into the country. No water drips from the mixture during these operations, and the manure is said to be remarkably homogeneous, and to admit of being easily spread in the fields. This manure is highly esteemed by the farmers of the region in which it is made, and the cost of preparing it is more than made good by the price at which it is sold.

Street-Sweepings.

It may here be said that in some cities, as in Boston, formerly, the sweepings from paved streets are thrown into heaps and sold to farmers for a trifle. At Boston these sweepings consist chiefly of mud or dust worn from the pavement, and from the earth in the cracks between the stones, together with horse-dung and an appreciable percentage of iron which has been rubbed off from the tires of wheels and the shoes of horses.

At Dresden, in 1890, according to Steglich, mere street-sweepings are deposited in heaps 80 feet long, 16 feet wide, and 6.5 feet high, which are forked over after having lain 6 months, and are at the same time moistened with water. The heaps are left for another term of 6 months, and their contents are then disposed of as "ripe compost." This ripe compost is described as a remarkably homogeneous, friable, earthy matter, moderately moist, and of dark color. It contains, among other things, about half its weight of sand and clay, and one-third its weight of water; only some 9 or 10 % of organic matter, 0.23 to 0.33 % of nitrogen, 0.37 to 0.46 % of phosphoric acid, 0.33 to 0.38 % of potash, 0.84 to 1.05 % lime, and 0.18 % of magnesia.

At Berlin in 1892, Vogel found that street-sweepings taken chiefly from asphalt pavement contained 40 % of water, 22 % of organic matter, and 38 % of ash. The fresh material contained 0.48 % of total nitrogen, 0.004 % of ammonia, 0.45 % of phosphoric acid, 0.37 % of potash, 1.89 % of lime, and 0.35 % of magnesia. In refuse from houses (dry dirt) which had lain in a heap for three-quarters of a year, and had rotted somewhat, he found 60 % of fine earth which contained 19 % of water, 20 % of organic matter, and 61 % of ash. There was in this fine earth 0.35 % of total nitrogen and 0.05 % of ammonia; beside 0.58 % phosphoric acid, 0.22 % potash, 8.92 % lime, and 1.74 % magnesia that were soluble in acids.

In certain parts of Paris, street-sweepings are sometimes collected by themselves in the dry season. The following analyses by Muntz and Girard relate to samples that were collected specially on the given dates: —

Per cent of	30 Dec. 1886.	3 Jan. 1887.	12 Jan. 1887.
Water	77.80	22.00	34.00
Nitrogen	0.13	0.63	0.47
Phosphoric acid	0.29	0.60	0.48
Potash	0.02	0.09	0.07
Lime	7.61	6.39	8.18
Weather	very rainy.	dry.	light rain.

As a rule, however, the street-dirt of Paris is different from that of most cities, since it is the custom there to throw into the streets by night all manner of refuse substances from houses, kitchens and workshops. In winter much ashes is thus thrown out. All this refuse is collected, together with such part of the street-sweepings as is not washed into the sewers, and thrown into heaps. On the average, some 2,600 cubic yards of the dirt are hauled out from Paris daily. The heaps of dirt soon become hot through fermentation and are greatly reduced in bulk as the organic matters in them are converted into humus. Meanwhile the material takes on a black color and becomes much more homogeneous than it was at first. As a general rule, it is only after this fermentation that the dirt is disposed of to the farmers. The fresh material is known as green dirt, and the fermented mass as black dirt. According to Muntz and Girard, the composition of the Paris street-dirt is as follows:

Per cent of	Green dirt, as taken from the carts.	Black dirt, after fermentation, from different sections of the City of Paris.		Black dirt, from Bordeaux.
Nitrogen	0.38	0.45	0.39	0.49
Phosphoric acid	0.41	0.59	0.45	0.58
Potash	0.42	0.52	0.29	1.22
Lime	2.57	3.75	2.92	...

At Rome, the refuse from houses and streets is thrown into great heaps which, according to Ceselli's observations, contain about 40 % of stones, earth, mortar, etc., 35 % of horse-dung, 20 % of vegetable refuse and 5 % of rags, paper, leather, bones and glass. These heaps undergo fermentation and putrefaction, and the matter at the centre of the heap passes into a condition known as "black butter," while the sides and tops of the heaps become earthy or loam-like. The following analyses are by Longi and by Freda:

	Black butter from an old heap, %.	Black butter from an old heap, %.	Earthy top of an old heap, %.	Tolerably new heap, %.
Water	34.10	31.62	19.50	15.03
Stones, etc.	2.81	16.24	7.51	5.30
Ashes	36.53	32.71	46.89	62.25
Phosphoric acid	0.78	0.40	0.54	0.77
Potash	1.18	1.30	1.09	2.29
Lime	9.73	4.71	6.43	1.10
Total nitrogen	0.45	0.34	0.31	0.47
Organic nitrogen	0.30	0.26	0.29	0.41
Ammonia-nitrogen	0.17	0.01	0.01	0.07
Nitrate-nitrogen	0.00	trace	0.01	trace

Poudrette.

Formerly, during many years, large quantities of night-soil were manipulated in one of the suburbs of Paris for the purpose of making "poudrette," and the process employed there has a certain historical importance, because the Parisian poudrette became in some sort a standard of comparison to which other analogous products were naturally referred. Some old quarries at Montfaucon, just outside of Paris, had been, by some slight alteration, converted into a series of basins or tanks. Night-soil was poured into the uppermost basin, where a good part of its solid contents sank to the bottom at once, while the liquid portions were made to flow slowly and methodically through a set of the lower basins, which served as receptacles to collect whatever solid matter the liquid held in suspension. The cleared liquid finally escaped through a fine sieve into the Seine.

Whenever a sufficient quantity of sediment had collected in either of these settling tanks, the liquid was run off from that tank, or, if need were, it was pumped over into the next basin, and the deposit was removed from the bottom of the tank to a great field contiguous to the establishment, and there spread out to dry. The layer of mud was harrowed from time to time to facilitate the drying. It need hardly be said that the product obtained in this way could not possibly have been so concentrated a fertilizer as those to which we are accustomed nowadays. But, on the other hand, all accounts agree that the stench from the works was wide-reaching and abominable.

Manifestly the process was radically vicious, and it is well to consider it carefully on that very account. The fact that the making of this poudrette was so long persisted in by the Parisian authorities shows how little was known, until very recently, of the true theory of manures; while the parallel fact that people could be found willing to pay money for a material of so little real value shows how hard beset farmers must have been before the days of guano and commercial fertilizers, properly so called. It teaches how greatly favored farmers are nowadays in having an abundant choice of cheap and powerful manures.

One good word, however, can be said in favor of poudrettes that were similar in character to the old Parisian product: their mechanical condition was excellent; and this was a very important matter at a time when, excepting rape-cake, hardly any other fertilizer shared this quality. A dry, inoffensive powder, that can be sown with seeds from a machine, must commend itself in numerous instances. Another point to be noticed is, that the Parisian poudrette was probably full of germs of useful micro-organisms. To this fact may justly be attributed the chief part of the good effects that were obtained when the poudrette was applied to the land; that is to say, it excited the fermentation and nitrification of the humus of the soil, and was in so far a source of biological rather than of chemical power. Several analyses of the Parisian (Montfaucon) poudrette have been published, as follows: —

	Water.	Organic Matter.	Total Nitrogen.	Ammonia.	Nitric Acid.	Phosph. Acid.	Lime.
Boussingault and Payen	41.4	...	1.56	...	...	...	...
Jaquemont	...	...	1.90	...	...	...	...
Soubeiran (1847)	28–32	29.00	1.78	0.73	...	3.73	...
L'Hôte (1848)	30.20	32.81	1.52	0.59	0.30	4.18	6.70

Barral, in 1863, reported that poudrette, as made at Bondy, near Paris, and in some other localities, from dried human excrement, weighed about 65 lb. to the heaped bushel, and contained 34 % of water and 1.4 % of total nitrogen. Large numbers of more recent analyses, by Aubin, show that French poudrettes, though somewhat variable as to their composition, usually contain, nowadays, from 1 to 2 % of nitrogen and from 2 to 6 % of phosphoric acid.

Muntz and Girard have noticed French poudrettes that contained as little as 0.46 % nitrogen, 1.21 % phosphoric acid and 1.29 % of potash, while others contain as much as 2.79 % nitrogen, 8.14 % phosphoric acid and 0.53 % of potash. On the average, they have found 1.6 % nitrogen, 3.00 % phosphoric acid and 0.50 % potash. It is to be understood, of course, that poudrettes have been made in many other places beside Montfaucon.

Generally, they appear to have consisted of the sediment from night-soil (either with or without the addition of small quantities of copperas, gypsum, alum, or the like) dried in the air; though in many cases the sediment seems to have been more or less diluted by the addition of peat, or peat charcoal, sawdust, coal-ashes, gypsum, or some other absorbent that had been added to facilitate the drying and mitigate the stickiness of the material. Of course the product must vary in composition according to the amount of inert matter that has been added to it, as well as according to the state of freshness of the night-soil employed. In the following table analyses are given of poudrettes that were formerly made at the cities named: —

Poudrettes, made at	Water.	Organic Matter.	Total Nitrogen.	Phosph. Acid.	Potash.	Lime.	Magnesia.
New York City, Lodi Manuf. Co. (reported by S. W. Johnson)	32 52	14.88	0.95	1.06	1.38	1.05	trace
	15.60	18.40	0.98	. . .	. . .	. . .	. . .
	25.62	14.80	0.95	. . .	. . .	. . .	. .
Hartford, Conn. (S. W. Johnson)	39.97	20.57	1.01	0.87	. . .	. . .	. . .
	60.01		1.06	1.05	. . .	. . .	. . .
Dresden,							
(Müller)	19.50	20.80	2.10	2.50	1.50	2.70	0.70
(Scheven)	18.42	11.25	1.34	. . .	. . .	. . .	. . .
(Bretschneider)	15.91	35.12	1.68	2.75	0.81	6.28	
Cologne (Grouven)	12.80	36.20	2.01	3.01	0.55	. . .	. . .
Brünn (Kohlrausch)	7-17	20-53	1.0-2.5	2.5-3.0	0.8-1.3	. . .	. . .
Königsberg (Klein)	. . .	31.00	1.73	1.57	. . .	. . .	. . .
Leipzig (Dietrich)	13.40	31.20	2.10	2.96	0.61	1.07	. . .
Metz (Stutzer)	27.71	25.87	1.48	2.95	0.64	. . .	. . .
Dorpat, Jama's process (Thoms)	. . .	. . .	2.35	3.50	1.04	. . .	. . .
Average comp. of modern German poudrettes (Wolff)	11.5	37.4	1.8	2.8	1.1	. . .	. . .

Blood Poudrette.

Sometimes poudrettes have been made by mixing solid excrement, or the solid part of night-soil, with blood from slaughter-houses, and drying the mixture. The product was naturally rich in nitrogen, and was doubtless a powerful manure, though apt to vary considerably in composition, as is shown by the following analyses: —

		Water.	Organic Matter.	Ash.	Nitrogen.	Phosph. Acid.	Potash.
Brünn (Kohlrausch)	1871 . .	9.38	74.10	16.52	9.03	0.87	0.64
	1871 . .	8.73	87.81	3.45	12.44	3.46	. . .
	1872 . .	7.94	32.44	59.62	2.09	2.60	0.88
Vienna (Kohlrausch)	1873 . .	7.76	42.79	49.45	4.42	. . .	. . .

Phosphate Poudrette.

Another class of poudrettes that contained considerable quantities of phosphoric acid were prepared formerly by mixing phosphates with the sludge from night-soil,— notably spent bone-black, which helped to dry the material. Analyses of these phosphatic poudrettes are as follows. In many of these cases the sediment from night-soil had doubtless been mixed with blood as well as with bone-black; or the mixture of blood and bone-black that is obtained in some processes of refining sugar had been added to the night-soil: —

Phosphatic Poudrettes made at	Water.	Organic Matters.	Nitrogen.	Phosph. Acid.	Potash.
Berlin (Lucanus)	8.22	48.69	7.14	14.10	. . .
	8.47	65.36	6.53	8.72	. . .
	12.26	43.13	3.22	3.73	. . .
Breslau (Hellriegel)	7.26	60.20	9.30	8.29	. . .
Hanover (Hellriegel)	20.48	25.23	2.51	15.88	. . .
	12.12	27.82	3.90	19.11	0.42
	9.04	34.26	2.65	16.98	0.36
Dresden (Fleck)	. . .	49.85	3.56	14.16*	. . .
Berlin (Heidepriem)	5.61	46.73	5.11	11.75	. . .
Vienna (Kohlrausch)	9–19	22–30	1.4–2.3	3.3–10.7	0.8–2.0
Paris (Voelcker)	25.20	26.14	3.35	17.17†	3.22‡

In the category of phosphatic poudrettes may be mentioned a product prepared by a secret process by one Thon, which attracted considerable attention among chemists some years ago. Whatever the cost of making the material may have been, its composition was excellent, as was shown by repeated analyses made by several chemists. These analyses showed the following per cent of substances: —

Water	10–12
Organic and volatile matters	30–40
Ash-ingredients	50–60
Nitrogen	4–6
Total phosphoric acid	10–12
Potash	1.5

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* Phosphate of lime. † Phosphates. ‡ Alkaline salts.

Nearly one-half the phosphoric acid, viz. 4.5 to 5 %, was soluble in water, and the remainder, excepting one or two per cent of ferric and magnesium phosphate, was in the form of precipitated phosphate of lime. One of the analyses indicated that 1.75 % of the nitrogen was in the form of ammonia, and that nearly half of one per cent of the nitrogen was in the form of urea. So large an amount of soluble phosphoric acid, taken in connection with the presence of 15 % of sulphuric acid in the ashes of the product, went to show that the process of manufacture may perhaps have consisted in adding superphosphate of lime to fresh excrements, perhaps with the addition of a little free sulphuric acid also.

Thon submitted his secret to the chemist Dietrich, who several times prepared small quantities of poudrette in accordance with the formula, and found that every particle of the nitrogen in urine could be preserved by means of it. Thon's poudrette was a dry, yellowish powder.

Ta-feu.

A product of Chinese invention, known as Ta-feu (Taffoë of the Germans), was prepared originally by kneading excrement and loam together, moulding the product into bricks and drying the latter in the air. A sample of a German preparation sold under this name, and consisting chiefly of peat and lime, has been analyzed by Klien. It contained 31 % of organic matter, 40 % of ashes, 1.7 % of nitrogen, and 1.6 % phosphoric acid. In a sample of so-called ta-feu marl, Klien found 4.4 % of organic matter, 57 % of lime and carbonate of lime, 0.32 % of nitrogen, and 0.37 % of phosphoric acid. It had been prepared, apparently, by slacking quick-lime with the liquid part of night-soil.

Processes of Evaporation.

If fresh urine were to be evaporated to complete dryness so carefully that none of its nitrogen should be decomposed, an extremely powerful fertilizer would be obtained; each 100 lb. of which would contain some 25 lb. of nitrogen, 4 lb. of phosphoric acid, and 5 lb. of potash and soda. But to obtain 100 lb. of such residue an amount of urine would have to be taken equal to all that is voided in a day by 1,000 men. (Stœckhardt.)

Way's analysis of dried solid excrement shows 88.5 % organic matter, 4.3 % phosphoric acid, 1.2 % potash, and from 4.3 to 7 % nitrogen. The fresh excrement contained from 20.4 to 26.8 % of water, and from 1.2 to 1.5 % of nitrogen. He estimated that each individual in a city would contribute to the sewage 0.25 lb. of solid and 3 lb. of liquid excrement every 24 hours.

According to Nesbit, if fresh human excrements, solid and liquid together, were thoroughly dried, each 100 lb. of the product would contain some 17 lb. of nitrogen, and 3 lb. of phosphoric acid, or in a ton there would be say 340 lb. of nitrogen and 60 lb. of phosphoric acid. Even sewage evaporated to dryness may contain, according to one of the English commissions, 30 % organic matter, 70 % ash ingredients, 6½ % nitrogen, 1¾ % phosphoric acid, and 1 % potash.

Dried Excrement.

Efforts have not been wanting to put the idea of evaporation into practical form, and in several German towns really good manure seems to have been obtained in this way, i. e. by acidifying with sulphuric acid tolerably fresh excrement which has been collected in barrels, and evaporating the material to dryness. The first five analyses in the following list are of poudrettes known to have been prepared in this way, and the other specimens appear to have been similarly treated: —

Composition of Dried Excrement.

	Water.	Organic and Volatile Matter.	Nitrogen.	Phosph. Acid.	Potash.
Milburn Co. (Voelcker) . .	10.49	59.69	6.5	5.12 (phosph. lime)	
Stuttgard (Soxhlet) . . .	....	....	7.52–9.96	2.73–3.50	....
Heidelberg " . . .	....	....	8.8–9.1	3.0–3.1	....
Augsburg " . . .	....	....	6.0–6.1	3.0–3.7	....
Munich (Soxhlet) from vaults	....	....	8.4–9.6	0.7–1.0	....
Berlin (Märcker)	....	....	4.69	4.05 (2.94 % soluble)	
" (Fittbogen) . . .	....	....	4.65	4.09 (3.16 % soluble)	
" (Ziureck)	....	....	4.65 (2.60 % soluble phosph. acid)		
" "	....	....	5.16	3.38	2.26
Münster (König)	....	....	5.59	3.27	2.48
Halle (Märcker)	....	....	5.00	2.91	2.70
Braunschweig (Schulz) . .	....	....	5.30	3.10	3.20
" (Fruhling) .	....	....	5.15	2.95	2.89
Hamburg (Ulex)	....	....	5.30	3.39	2.31

Similar poudrettes prepared from tolerably fresh excrements, as obtained by Liernur's pneumatic process, have been found to contain the following percentages, as obtained at

	Water.	Nitrogen.	Phosp. Acid.	Alkalies.
Dortrecht (Burgh) . .	12.0–22.5	1.6–7.0	1.6–4.0	. . .
Hague	16.84	7.80	2.0	. . .
Breda	22.10	6.69*	1.1	. . .
Dublin (E. W. Davy) . .	15.86	6.32	6.85 (phosphates)	
Wiesbaden (Fresenius) .	14.82	7.56†	2.66	3.10

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* (4.25 % as ammonia)

† (5.7 % as ammonia)

It does not appear as yet whether any legitimate money profit has been gained by making these poudrettes. Indeed, it is doubtful on the face of the matter whether profit can possibly be gained by burning fuel to drive off the large amounts of water with which even fresh excrements are diluted, for the sake of getting the fertilizing constituents. The probabilities are, that the labor expended and coal consumed in making such poudrettes must cost more than the dried excrement is worth. Perhaps the making of them may have depended primarily upon efforts of the municipal authorities to find some outlet for the night-soil.

There was no sense, at all events, in making an English product known as "sulphated urine," which was prepared some years ago by adding to stale urine enough sulphuric acid to neutralize the ammonia, and then evaporating the liquid to dryness. For although the dried sulphated urine was really rich in plant-food, and was an efficient manure, it was not worth the cost of manufacture. A similar remark will apply to a process tried much more recently in Germany, by which the liquid portion of night-soil was evaporated in vacuum pans.

Chodzko's Process of "Graduation."

A more reasonable plan, putting sanitary considerations aside, was tried at one time, outside of Paris, by an inventor named Chodzko, who sought to save the fertilizing matters in the actually liquid part of the night-soil, which had previously been allowed to run to waste. To clarify and disinfect the liquid there was added to it either sulphate of magnesia or a mixture of the magnesium sulphate and sulphate of iron, together with a little tar, and potashes enough to destroy the acid reaction of the mixture. The clear liquid was then subjected to a process of evaporation which consisted in making it trickle over a large surface of fagots held up in a framework, — as in the well-known process of concentrating weak brines by "graduation," — and finally beating the fagots to detach the incrustations which had formed upon them. In good weather, new portions of the liquid were run in upon the fagots two or three times a day, and after the lapse of a fortnight or three weeks in summer, or of two months in winter, the twigs were sufficiently incrusted to be left to dry out. On analysis, the fertilizer beaten from the fagots showed the following percentage composition: —

Organic Matter.	Water.	Sand and Clay.	Magnesia and Oxide of Iron.	Total Nitrogen.	Ammonia.	Nitrates.	Phosph. Acid.	Lime.
53.53	17.75	4.50	4.50	4.20	0.65	trace	4.48	4.10

The product was distinctly superior to ordinary poudrette, such as was then prepared at Paris.

Podewils' Scheme.

Baron Podewils proposed, as one method of treating fresh excrements, 1st, to prevent them from putrefying by means of smoke; 2d, to dry the matter down to about half its bulk by artificial heat; then to mix with it absorbents, such as coal-ashes, peat-powder, soot, or the like (even finished poudrette would answer); and to mould the plastic mixture into bricks which could be dried in the air. Finally, the dried bricks were crushed to powder. The following analyses, by Wein, relate to such poudrette as this, and to the making of it.

	Excrements dried down without any Addition.	Half-dried Paste.	Half-dried Paste after Addition of Ashes.	Finished Poudrette prepared with Ashes and Soot.
Water	9.01	42.69	38.57	7.65
Organic and volatile matter	59.13	38.58	35.67	68.78
Ash-ingredients	31.87	18.73	25.76	23.57
Nitrogen	10.65	7.34	7.04	5.32
Phosphoric acid	4.48	2.54	2.18	3.90

Excluding water in each case, the dry substance contained per cents of

	Excrements.	Half-dried Paste.	Paste and Ashes.	Finished Poudrette.
Organic and volatile matter	64.97	67.31	58.07	74.47
Ash-ingredients	35.03	32.69	41.93	25.53
Nitrogen	11.89	12.80	11.45	5.76
Phosphoric acid	4.81	4.43	3.55	4.22

Treatment with Sulphates.

Sulphates of one kind or another, particularly sulphate of iron (copperas), have often been used for treating night-soil. In most European cities, where it has long been customary to exercise great care in emptying privy vaults in order to avoid the offensive gases which are liable to be given off when the contents of these receptacles are disturbed, it is not unusual, as a preliminary precaution, to throw into the vault a quantity of a solution of ferrous sulphate, or of some other disinfecting agent, and then to pump out the muddy liquid into a tight wagon by means of force pumps, or to draw it out into great iron cylinders in which a vacuum has been established by the condensation of steam. Care is taken to prevent the escape of offensive gases into the air, — sometimes by compelling the foul air from the pumps to pass through a little stove full of burning charcoal, by which means the odor is destroyed.

Of course, the sulphate of iron, when thus used, arrests a large quantity of ammonia, by converting the carbonate of ammonia into sulphate, though its special merit in this case depends on the fact that it reacts upon sulphuretted-hydrogen and ammonium sulphide and destroys the foul odor of these substances. It is as a disinfecting agent rather than as a fixer of ammonia that copperas is here used. It acts also as a germicide, to destroy the micro-organisms which cause fermentation and putrefaction, and to prevent their growth also. Thus it is, that, when applied to fresh excrements, copperas acts as a preservative, and hinders their decay.

According to Pettenkofer, if fresh excrements were to be treated, immediately and methodically, with a solution of copperas (1 part in 2 or 3 parts of cold water), less than an ounce of the salt per head and day would be sufficient to prevent the materials from undergoing ammoniacal fermentation. Excluding winter weather, when no disinfection would be needed anyway, a dozen or fifteen pounds of copperas, obtained at a nominal cost, would suffice for treating the excrements of an individual for a year. It is to be said, however, that, as regards night-soil, the deodorizing powers of copperas are but partial; it arrests sulphuretted hydrogen, it is true, but has no action upon a variety of other offensive matters which are always present.

Action of Copperas on Plants.

In view of the fact that ferrous compounds are apt to be injurious to plants, it is to be presumed that, as a general rule, it might be well not to apply night-soil that had been treated with copperas immediately to crops, but to leave it exposed to earth and air long enough for the ferrous compounds to become converted to the ferric condition, though there are excellent experiments by Kellner which show that, practically, field crops are not ordinarily interfered with by the ferrous sulphate which has been used to deodorize night-soil. This immunity probably depends on the extreme dilution of the copperas thus admixed with the fæcal matter and on the rapid oxidation of it when strewn upon the land, for A. Mayer has shown that, with the exception of oats, the cereal grains are apt to be more or less injured by applications of ferrous sulphate. He found that, in respect to their sensitiveness toward copperas, the cereals might be placed in the following order: wheat, rye, barley, oats. He notes that this result is in accord with a popular impression that oats are better fitted for iron soils than either of the other grains and than most of the true grasses.

Since a very early period sulphate of iron has often been used upon ordinary manure-heaps to hinder their decay, and to prevent a real or supposed loss of ammonia; and so have pyritous coal and pyritous lignite, from which sulphate of iron is formed by the action of the air. It was thought at one time long ago — and the idea has recently been resuscitated in respect to ferrous sulphate — that the pyritous refuse from mines of lignite was specially valuable as a fertilizer, but the probabilities are that the iron sulphate did good indirectly either by virtue of sulphate of ammonia which it may perhaps hold in combination, or because it served to decompose lime compounds in the soil with formation of gypsum, which in its turn acted as if it had been applied directly.

Pichard in his experiments found that gypsum was much more effective than copperas for preventing the loss of nitrogen from clay soils, and equally effective with it on light calcareous loams, but in sandy soils gypsum was less efficient than copperas, because it is less soluble. He argues that copperas may do better service than gypsum on dry, sandy soils deficient in clay, lime and ferric oxide, but that on all other soils gypsum is to be preferred.

For fixing the ammonia, which might otherwise be lost from manures in a condition of hot fermentation, copperas may be valuable, as has been said, but on account of its antiseptic properties it might do harm to slowly decomposing organic matters and in the compost-heap. Most salts of iron are inimical to the micro-organisms which cause the decay and destruction of organic matters, though it has been noticed that lactate of iron (and other salts of iron with organic acids?) may promote nitrification.

On the other hand, carbolic acid that has been used for disinfecting excrements may do harm by hindering the germination of seeds. Thus Kellner found that the presence of 0.25 % of carbolic acid hindered the germination of barley, while 1 % killed the seeds. So too, a 0.1 % solution of carbolic acid suspended the germinative power of wheat, and a 0.05 % solution that of soy beans. By field experiments also it was found that wheat, barley and buckwheat suffered harm when sown soon after the land had been manured with diluted night-soil that had been treated with carbolic acid. But in case the carbolic night-soil was ploughed under in October and left during the winter to the action of the weather, it exerted hardly any appreciable injurious action upon seeds sown in the spring.

Sulphate of zinc, also, and chloride of zinc, have sometimes been used to disinfect night-soil, in much the same way as sulphate of iron.

Action of Gypsum on Urine.

A fertilizer called "urate" was at one time made in England by adding gypsum to urine, and collecting and drying the precipitate produced. This precipitate contained a considerable proportion of the phosphoric acid of the urine, though very little of its nitrogen; and since the principal value of urine depends upon the nitrogen contained in it, the process was not one of any merit.

Gypsum has often been mixed with night-soil, with the idea that it would decompose carbonate of ammonia and hold the ammonia as a sulphate. It is inferior to copperas not only in this respect, and because it does not destroy the odor of sulphuretted-hydrogen, but because as a germicide it is not to be compared with copperas. Moreover, it has no power to mitigate the peculiar offensive odor of putrid urine, which is due to the presence of some substance quite distinct from ammonia.

At one time, many years ago, sulphate of ammonia was prepared as a commercial product by filtering fermented urine through gypsum; but the process was offensive and inconvenient, and would be much too costly nowadays, when ammonia is to be had as a waste product at gas works. Indeed, even if the gas-liquor were not to be had, it would be cheaper to obtain ammonia from fermented urine by way of distillation, than by means of the old gypsum process.

Manufacture of Ammonium Salts from Urine.

In view of the ready volatility of ammonia, it would be, comparatively speaking, easy and inexpensive to procure this substance from fermented urine by way of distillation, as is done in the case of the ammoniacal liquor of gas-works, if it were only possible to collect large quantities of urine without offense, or even if it were economically practicable to control the fermentation of urine so that it could be brought to the factory in a condition of tolerable freshness. As has been shown already, on heating water which contains ammonia, almost the whole of the ammonia will go off with the first fifth of the water that evaporates. Hence it would only be necessary to distil off little more than one-fifth part of the bulk of the fermented urine in order to expel all the ammonia that was contained in it, which would amount to something like one-fifth of one per cent of the original liquid. The distillate might be made to pass directly into sulphuric acid to form sulphate of ammonia, or it might be led into another batch of urine, which could thus be converted into a more concentrated solution of ammonia, fit perhaps to be mixed directly with the acid.

One idea, suggested by Bolton and Wanklyn, was to lead the ammoniacal fumes arising from the evaporation of urine into a box filled with trays charged with sulphate of lime. By the action of the carbonate of ammonia on the lime sulphate, there would be formed carbonate of lime and sulphate of ammonia. But on heating this mixed product, carbonate of ammonia would exhale, and could be collected, while sulphate of lime would again be formed. Another plan was to lead the ammoniacal fumes from the urine into a clear solution of superphosphate of lime. From this liquor, after evaporation, a double phosphate of lime and ammonia could be made to crystallize out.

In distilling stale urine it would be well to add to it a small quantity of milk of lime, or even chalk, in order to decompose any phosphate, sulphate, chloride, or other non-volatile ammonium salt, that might be present. This lime would combine with the phosphoric acid in the urine, and render it insoluble, so that this constituent could be saved as well as the ammonia. It being thus easy to save the only two ingredients of urine that have an appreciable value, there is really no need of thinking of a process so troublesome as that of evaporating urine to dryness as a means of utilizing it.

Urine may be kept Fresh.

Several chemists, notably Alex. Müller and Grouven, experimented many years ago with the view of finding some means of preserving urine so that it might be collected for the purpose of being put to use by the process of distillation just now alluded to. So far as the mere prevention of putrefaction was concerned, they found that urine could be preserved in several ways long enough for the purpose now in question. The presence of almost any free acid, or of an acid salt, in urine, will prevent the action of the ferment which causes urea to change to carbonate of ammonia. Nitric acid is specially powerful, sulphuric acid much less so.

Ferrous sulphate and the sulphates of copper and zinc are effective, and so are carbolic acid, and coal tar, and tannin. As is now known, almost any germicide would answer the purpose. In case fresh urine were thus acidified, it would be an easy matter to neutralize the acid at the ammonia works, and to prepare the urine for distillation by mixing with it a quantity of urine that was already undergoing the ammoniacal fermentation, and allowing it to stand for a day or two. It is manifest, however, and the point was freely admitted by Müller, that special appliances would be required for mixing the preservative agent with the fresh urine, and that the tanks and other apparatus used would have to be frequently and carefully cleaned.

In one word, it appears that, beside all the ordinary costs of collection and transportation, a good deal of trouble would have to be taken in order to obtain a supply of urine without offense, and it is precisely this trouble which there is no need of taking so long as ammonia can be obtained at less cost from the products of the distillation of coal.

Lack of Raw Material.

Grouven, on the occasion of his examination as to the possibility of utilizing the product of the public urinals at Cologne, encountered yet another difficulty, viz. that of obtaining enough of the raw material (fresh urine) to keep a factory in profitable operation. At Cologne he found that 45,000 cwt. of urine could be collected in a year, which was at the rate of 40 lb. for each inhabitant, or nearly 10 % of all the urine voided by the population of the city. Supposing the whole of this urine were evaporated, it would be possible to get 4 %, i. e. 1,800 cwt. of dry residue, and if the manufacturer were to double this quantity by adding to it acids, or superphosphate, there would still be no more than 3,600 cwt. of matter to be sold, — a quantity so small that a factory could hardly be maintained upon the profits from it. He estimated that at least 10 times the given quantity of urine would be needed, under the conditions of which he wrote, in order that a profitable business could be based upon it.

When considerations such as these come in to increase the inherent difficulties of the subject, — viz. those that depend on the offensive odor and small value of the original materials, and their rapid deterioration by fermentation, it can be seen clearly enough why it is that manufacturers of manures are no longer much encouraged to grapple with the problem of utilizing night-soil; let alone the fact that the conviction gains ground almost everywhere that the best way of dealing with the filth of cities is to dilute it enormously with water, and throw away the dirty water as speedily as may be possible.

Manufacture of Sulphate of Ammonia from Night-Soil.

Inasmuch as night-soil usually contains less nitrogen than urine does, it is in so far a less advantageous source of ammonia than urine would be if it were procurable. But it has occasionally been found practicable to prepare sulphate of ammonia from the liquid portion of night-soil in certain localities, though the amount obtained in this way has in modern times been very small, as compared with that made from gas liquor. At Paris, especially, it it has long been customary to distil considerable quantities of the liquid part of night-soil for the sake of its ammonia, something like 8 lb. of sulphate of ammonia being obtained from 100 U. S. or wine gallons of the liquor; in other words, 10 kilos. of the sulphate for every cubic meter (1000 litres) of the liquor.

More recently, a reasonable plan for saving ammonia from the liquid part of night-soil has been proposed by Ketjen, and put in practice at Amsterdam, it is said with profit, at an establishment fitted to work over 250 cubic metres of the liquid per diem. A small quantity of milk of lime is added to the liquid, which is then heated in a boiler to 112° C. whereby the ammonia is wellnigh completely expelled and the night-soil thoroughly disinfected. In the course of a year 72,100 kilos. of sulphate of ammonia were obtained in this way from 8,750 cubic metres of the liquid. The average composition of the original liquid was, dry matter 2 %, total ammonia 0.33 %, phosphoric acid 0.13 %, and potash 0.07 %. Of the ammonia, nearly 0.2 % was in the free state, 0.08 % was in the form of ammonium salts, and 0.06 % in organic combination. By means of a filter-press, the solid matter left in the liquor after the expulsion of the ammonia is obtained in the form of cakes containing 41.6 % water, 52.3 % carbonate of lime, 0.52 % nitrogen (of which 0.0323 % is ammonia), 1.16 % phosphoric acid, and 0.16 % potash.

Magnesium Processes.

Long since, it was a favorite idea among chemists that both ammonia and phosphoric acid might be precipitated from fermented urine by means of a magnesium salt. One suggestion was, even, that a magnesium salt might be mixed with fresh urine, which should then be made to ferment. In either event, the insoluble double phosphate of ammonia and magnesia, so familiar to analytical chemists, was to be thrown down as a precipitate which could be collected and used as a manure. The fertilizing power of this precipitate is undoubted, since it has been proved by numerous experiments.

There are several difficulties which prevent the practical application of this idea. The double phosphate is a crystalline precipitate, which, when formed in presence of much water, separates out very slowly. So much time is required in order that it may be deposited from a liquid so dilute as urine is, that a very large number of tanks would be needed at a factory in order that the contents of any one of them could be left at rest long enough to insure complete deposition of the precipitate. Moreover, the presence not only of a soluble magnesium salt, but of an excess of some base, such as hydrate of magnesia or hydrate of lime, is necessary to insure the complete precipitation of the ammonia.

Several inventors have sought to insure the precipitation of all the ammonia by adding phosphate of magnesia to stale urine, or night-soil, or sewage, and it would be easy to prepare any quantity of the magnesium phosphate at small cost from superphosphate of lime and waste chloride of magnesium, which is procurable at Stassfurt. Sometimes it has been suggested that phosphate of soda and a magnesium salt might be mixed with the urine or night-soil, or a mixture of superphosphate of lime and a magnesium salt. One proposition looking to the more rapid separation of the double phosphate was to filter the fermented urine through a bed of peat charged with sulphate of magnesia. One trouble is, that the double phosphate is not so completely insoluble in saline solutions as it is in pure water or in water charged with ammonia.

Use of Alum and Sulphate of Alumina.

Though rather inefficient disinfecting agents, the sulphates of alumina have sometimes been employed in the preparation of poudrette from night-soil. Probably the process of Forbes and Price, described under the head of Sewage on a subsequent page, would be better for this purpose than sulphate of alumina.

Admixing of Excrement with Lime.

The use of lime for preserving fresh excrements has repeatedly attracted attention, and many futile efforts have been made to prepare merchantable fertilizers by means of it.

Mosselmann, in France, proposed the following process. Quicklime is slaked with half its weight, or with an equal bulk of urine, and the dry powder thus obtained is mixed with solid excrement in the proportion of 2 parts excrement to 2.5 parts of the slaked lime. The mixture is ready for transportation the moment it is prepared, and it contains all the ingredients of the original urine and solid excrement, excepting a quantity of water which was evaporated by the heat disengaged in the act of slaking. The amount of water thus lost is about equal to the weight of the lime. With the water, some small traces of ammonia escape that existed ready formed in the matter treated.

Of course a large quantity of ammonia would be expelled by the lime if the latter were added to old night-soil that had undergone fermentation. In order to obtain the best results, the process imperatively requires that the excrement and the urine shall be treated while still fresh.

It was claimed at one time that the dry product could be kept indefinitely without undergoing change, but it appeared subsequently that a certain amount of change does slowly occur. The process has been modified somewhat to meet the case where a large quantity of urine is to be treated; for when urine alone is mixed with lime, the latter can be made to absorb, by repeated additions, as much as three times its own volume of the liquid, while something more than half of the water of the urine escapes in the form of steam.

In operations carried out upon the large scale, it was found that even in winter one part of lime could be made to absorb three parts (by bulk) of mixed solid and liquid excrement. But in summer somewhat more water went off in the process of slaking, so that the final product contained only 20 % of lime. The process has evidently a certain degree of merit, and it is easy to admit that cases may occasionally arise, as at prisons, barracks or factories (gas works?), where it might be employed with advantage in the interests of agriculture. From the large amount of lime required, however, it would be very difficult to put the process in practice as a sanitary measure, looking to the economical purification of cities. The difficulties attending the handling and marketing of large masses of material would practically be insuperable. One of the sewage commissions of the city of Berlin computed that, if the process were applied to a city of 550,000 inhabitants, nearly a million and a half bushels of quicklime would be needed every year.

Practical experience at the farm has still to determine whether there may not be some localities, as in regions of heavy clay lands, for example, where limited amounts of the limed excrement would be valuable enough as manure to permit the material to be transported to moderate distances.

Analyses of the product as obtained (I) from Mosselmann himself, and (II) as prepared in two different German towns, indicated the presence in it of the following per cents of

	I.	II.	
Water	34.00	46.00	30.00
Organic and volatile matters	18.38	10.00	9.00
Nitrogen	0.69	Not determined.	
Phosphoric acid	0.19	1.06	1.23
Lime	24.40	30.30	41.00
Magnesia	0.63	0.77	0.28
Potash	0.28	0.04	

Hervé-Mangon reports, as the result of numerous analyses, that Mosselmann's product hardly contains half of one per cent of nitrogen.

A. Müller's Lime-process.

About the same time that Mosselmann published his process in France, the chemist Alex. Müller was occupied with experiments upon the action of lime, at Stockholm. Müller found that, when fresh fæces are mixed with lime, only an insignificant quantity of ammonia is given off. He proved, indeed, by numerous experiments, that fresh fæces do not contain, on the average, more than 0.1 % of ammonia.

Müller, like Mosselmann, found that it is easy to convert solid excrement into a dry powder, fit to be transported, by the use of lime. He urges, however, that the proportion of lime should be kept as small as possible, and that it will usually be best to resort to air and the sun's heat in order to complete the drying. He suggests also that, whenever the process is applied to night-soil that has begun to ferment, an arrangement should be provided for saving any ammonia which may be evolved, by causing it to come into contact with some acid absorbent, such as superphosphate of lime, peat wet with sulphuric acid, or the like.

A German mechanic, named Schur, seeking to bring Müller's ideas into practical use, constructed a closet in such manner that, while the fæces and urine were separated, the fæces were covered with a small quantity of powdered lime mixed with a little fine charcoal, something in the same way that dry earth is now applied in the earth-closet. A sample of the dry product from one of these lime-closets was found to contain 2 % of nitrogen and 4 % of phosphates.

The mode of action of the lime upon the excrement is similar to its action upon other forms of nitrogenized organic matter, as has been set forth under the head of Fish-Waste. Insoluble compounds of lime and organic matter are formed, which, so long as they are kept dry, resist decay and putrefaction. A small incidental advantage is that the lime retains the phosphoric acid of the urine also, though the amount of it is never very large (according to Müller, the proportion of phosphoric acid in fresh urine may vary from 0.1 % to 0.3 %). For that matter, Müller found that the phosphoric acid in fresh urine may be completely precipitated by adding a small quantity of a soluble lime salt and a little hydrate of lime, i. e. enough to make the liquid alkaline.

The evaporation of water from the excrements by the heat developed during the slaking of the lime is an important consideration, of course, but it is altogether subordinate to the union of the lime and the organic matter on which the preservation of the material depends.

It is noteworthy that the use of lime for preserving excrement is a very old idea, and that beside the efforts above mentioned, numerous other attempts have been made to put it in practice.

Sir Humphry Davy, in his Lectures delivered in London at the beginning of this century, says: "The disagreeable smell of night-soil may be destroyed by mixing it with quicklime. If exposed to the atmosphere in thin layers, strewed over with quicklime, in fine weather, it speedily dries, is easily pulverized, and in this state may be used in the same manner as rape-cake, and delivered into the furrow with the seed." As will appear further on under the head of Flocculation by Lime, there can be little doubt that lime must act to promote the drying out of night-soil in the air since it would tend to destroy a peculiar muddiness and stickiness which ordinarily hinders it not a little from drying.

From a subsequent paragraph it is to be inferred that Davy believed that the Chinese use quicklime in this way; and it is well known that quicklime is often placed in coffins in China to prevent or retard the decomposition of the corpse. As long ago as 1802, Estienne proposed to prepare manure from night-soil by mixing its solid portion with lime, and drying the mixture in the sun. Payen at one time had much to say upon the subject.

CHAPTER XXIV.

POTASSIC MANURES.

It will be observed that the subjects of the chapters immediately preceding — notably Dungs, Composts, and Organic Matters — have been treated of primarily as nitrogenous manures. There remain to be considered several mineral substances which are employed as fertilizers, and among them the compounds of potash may fairly be regarded as most important.

As has been seen already, potassium is absolutely necessary for the growth of plants. Indeed, there must be a tolerably large supply of the compounds of this element within reach in order that the plant may prosper. Even those plants which grow in or near sea-water contain a comparatively large proportion of potash. At a very early period in the history of chemistry, potash was known as the "vegetable alkali," because it was obtained from the ashes of plants. The purpose of this name was to distinguish potash from soda, which was called the "mineral alkali." We know now, even more clearly than our forebears did, that soda is seldom found in large quantity in ashes, and manifold experiments have shown that it is a substance of little or no importance for the growth of plants.

There is naturally a good deal of potash in the soil, as follows necessarily from the familiar fact of its occurrence in the ashes of plants. Most of this potash comes from the decomposition of feldspar, that is to say, of orthoclase or potash-feldspar, which is a silicate of alumina and potash, but some of it comes from the decomposition of mica and other silicious minerals. Nearly all clays and clayey soils contain some potash. Risler and Gasparin found in many specimens from 0.3 to 0.7 % of it, although it is true enough that some of the better kinds of kaolins and porcelain clays are esteemed in the arts because they are practically free from potash. It is true also of agricultural practice that clays are occasionally met with which are as poor in respect to potash as the worst kinds of sandy soils. (Voelcker.) Nevertheless, as Schloesing and Perrey have shown, the particles of true plastic clay, which can be floated out from ordinary soils by washing with water, almost always contain a comparatively large proportion of potash, viz. from 2 to 5 %, sometimes even 7 % or more; and this remark is true of the "clay" extracted from silicious and calcareous soils, as well as of that obtained from loams proper. One reason why clay soils are strong, in the sense that they exhibit enduring fertility, is that they usually contain much potash. In several rocky and barren regions in northern and eastern New England, it is noticeable that the occasional farms are usually situated upon slopes or ridges of glacial clay.

Hilgard, who has tested many virgin soils in this country for "available potash," i. e. for the proportion of this substance which can be dissolved by hydrochloric acid of about 1.115 sp. gr., heated on a water-bath during 5 days, has observed in a large number of cases that the percentage of potash seems to vary with the proportion of clay in the soil. In clay soils, the percentage of potash is high, and in sandy soils it is low, and since subsoils are ordinarily more clayey than surface soils, their potash percentage is almost invariably higher than that of the soils above them. Heavy clay upland soils and clay loams contain from 0.5 to 0.8 per cent of potash, lighter loams contain from 0.3 to 0.45 %, and sandy loams less than 0.3 %. Sandy soils of great depth may contain less than 0.1 % of potash and yet be productive and durable, provided the soil is adequately supplied with phosphoric acid and lime. Virgin soils containing less than 0.06 % of potash seemed, in all cases that came under Hilgard's observation, to be deficient in available potash, and the application of potassic fertilizers to such soils was followed immediately by heavier crops. But since few soils fall below this minimum, the inference is that potassic manures are not the first to be sought for after a virgin soil has become tired by exhaustive culture. The universal preference given to phosphatic and nitrogenous fertilizers at the West and the South is in accord with this inference. (Hilgard.)

It is to be noticed that even so small a proportion of potash as 0.1 % will amount to 3,500 lb. to the acre, on the assumption that an acre of land, taken to the depth of 1 foot, weighs 3,500,000 lb., and that only a part of the total potash contained in the soils, in the form of refractory rock silicates, would dissolve in the acid in which the soils were soaked.

Amount of Potash in Rocks and Minerals.

Some of the volcanic rocks are rich in potash. A variety of rock called palagonite, found upon the sides of Ætna and Hecla, contains so much potash, and decomposes so readily, that it has sometimes been used as a manure. But for the recent discovery of better sources of potash, this rock might perhaps have been profitably transported to considerable distances for fertilizing purposes. The proportion of potash (K_2O) in various common minerals may be set down roughly as follows: feldspar (orthoclase), 12 to 17 %; mica, 3 to 5 %; albite (soda feldspar), 1 or 2 %; basalt, 0.75 to 3 %; clay slate, 1 to 4 %; good clayey loams, 1.5 to 4 %.

The nature of the change which may occur during the disintegration of feldspar is well shown by some analyses of Crasso: —

	Original Feldspar.	Decomposed Feldspar.	Matters Removed.
Silica	65.21	32.50	32.71
Alumina . . .	18.13	18.13	. . .
Potash	16.66	2.80	13.86

Why the Ocean contains Sodium rather than Potassium Compounds.

In the process of disintegration — technically known as "kaolinization" — by which clay is formed from feldspathic minerals, there are produced small quantities of solutions of silicates and carbonates of potash and soda, which speedily react upon compounds of lime and magnesia in the soil to form the insoluble, hydrated, zeolitic silicates which serve to fix potash and to retain it in the soil, as has been explained in Chapter VIII of Vol. I. A large part of the potash which in ordinary soils is available for crops appears to exist there either in combination with silica, alumina and lime, or as a double humate.

The importance of the existence of these complex silicates and humates cannot be too strongly insisted upon. Were it not for their restraining power, much of the potash now in the soil would have been washed out long ago and carried into the sea; for, excepting the silicates and humates, all the ordinary potash salts are readily soluble in water. It is precisely because soda is less readily retained than potash is by the double silicates in the soil, that the sea is salt with chloride of sodium, and not with chloride of potassium. Chloride of sodium is dissolved out from the soil and carried away to the sea by the ground-water more readily than any other saline substance. The water of the ocean holds in solution nearly 4 % of saline matter, rather more than three quarters of which is common salt. Next to the sodium chloride, salts of magnesium and calcium are present in sea-water in the largest proportion, while the quantity of potassium chloride is no more than about 4 % of the total solid matter.

It was observed long ago by the mineralogists, that, where silicates of potash and of soda exist side by side in the same mineral mass, and suffer decomposition together, the soda compound often loses its alkali rapidly, while the potash does not thus go to waste. Thus, Struve found in a phonolite (a feldspathic rock), —

	Potash.	Soda.
In its natural undecomposed condition . . .	3.45	9.70
When somewhat decomposed	5.44	3.26

A basalt —

	Potash.	Soda.
In its natural condition contained	1.35	7.35
When decomposed it contained	2.62	2.31

On digesting many virgin soils in hot, strong hydrochloric acid, Hilgard found as a rule that decidedly less soda than potash was obtained. The percentage of soda extracted by the acid was commonly from one-eight to one-third of the percentage of the potash. It is to be noticed that the double silicate of lime and alumina, and the double humates also, which hold the potash in such condition that plants can obtain from them a supply of this article of food, are usually found only in the finely divided earth or loam which constitutes the soil properly so called, and that at the best the store of available potash will be comparatively speaking small unless the soil contains a good deal of decomposing feldspar, or something such. Hence, whenever crops are taken from the land, the stock of potash may after a while be exhausted if no steps be taken to renew the supply. In fact, from the economic point of view, potash is the most important ingredient of manures after nitrogen and phosphoric acid.

The Soils of Arid Regions usually contain much Potash.

It to be remarked that a much larger proportion of potash — and for that matter of lime and magnesia, and even of soda — is found in the soils of arid regions than in those of countries of abundant rains. From the very fact of the absence of leaching by rain, the chemical reactions which occur in soils which are seldom moistened are favorable for the production of the double silicates which fix and hold potash, etc., as has been already explained. Hence the great and enduring fertility of Californian soils in respect to grain-crops, and to all kinds of crops when the land is irrigated.

Much Potash is returned to the Land.

Practically, a great deal of potash is returned to the land upon most farms, in the form of stable-manure, especially where pains are taken to absorb all the urine by means of straw; as well as in the refuse from crops, and in composts of one kind or another prepared from vegetable matter.

It is not with potash as it is with phosphoric acid. Potash does not accumulate to such an overwhelming extent in seeds and fruits as phosphoric acid does, nor in the animal body either. Hence, in general, in all well cultivated districts a much larger proportion of the potash that has been taken from the land is returned in the form of manure than is the case with phosphoric acid; and in consequence of this fact, considerable difference of opinion has existed as to the utility of buying potash compounds for manure.

The truth of the matter seems to be, that in well tilled, highly cultivated regions, where the land is dunged heavily, and especially where the rocks from which the soil has been produced are feldspathic, there is not apt to be any marked deficiency of potash in the soil.

Soils that respond to Potassic Manures.

On the other hand, in countries where the land gets but little manure, and particularly in localities where the rocks are of such character that they can supply only a comparatively small proportion of potash by their disintegration, as is the case not infrequently in the immediate vicinity of Boston, the benefits derivable from an application of potash to the soil may sometimes be great and immediate.

Almost anywhere upon the drier, lighter portions of the gravelly "drift" soils of New England, a dressing of potassic manure, especially carbonate of potash, such as occurs in wood-ashes, will justify itself at once. There was a striking illustration of this fact in experiments made some years since at the Bussey Institution, and published in the first volume of its Bulletin. Even in England the idea prevails that potash is liable to be wanting in light sandy lands (Voelcker), and somewhat similar remarks have often been made with regard to the soils of special localities in Europe.

For growing sugar-beets on light sandy soils, in which potash is generally deficient, and on soils which are in rather poor agricultural condition, mixtures of sulphate of potash and superphosphate of lime have not infrequently done excellent service. The moor-land of North Germany in particular, when thoroughly drained, is grateful for potassic manure. Thus on a drained and gravelled moor which gave 7 measures of rape-seed upon an unmanured field, 17 measures were got by means of phosphatic-fertilizers, and 47 measures by means of mixed potash salts and phosphates. Grass also and the cereal grains are greatly benefited on moor-land by potash salts. But, as a rule, potash seems to be comparatively little needed upon the rich farming lands of the Old World; although every little while instances are reported where profit has been got from the application of potassic fertilizers, especially on light soils, and with crops that stand in special need of this constituent. Thus, in a recent description of certain farm-land in Scotland, not far from Edinburgh, it is laid down as proved that "clover-sickness," as manifested in that locality, is caused by a lack of potash. At all events, those farmers of that region who have applied Stassfurt potash salts to land formerly clover-sick, now raise splendid crops of clover. And they notice that their clover is no longer thrown out in the winter months, as was apt to be the case before potash was used, probably because the plants can now become sufficiently well developed before the frosts set in to cover and shield the land.

Voelcker urged that while on light land and on some exceptional kinds of poor clays clover is greatly benefited by applications of potash salts and superphosphate, no such advantage is gained by using these fertilizers on most clays. It needs to be said, however, as Lawes and Gilbert have shown, that no matter how useful for clover potash compounds may be in general, they are not competent to cure clover-sickness in all cases, for it has been proved that the failure of clover is often due to some other defect in the land than a lack of potash or of any other ash-ingredient.

Lawes and Gilbert have urged that the liability of land to become exhausted of potash will naturally be greater on high-lying permanent mowing-fields than on land which is made to produce crops of wheat or barley, for the grain-crops are pretty sure to receive, in the form of manure applied at some period in the rotation, their fair share of the straw of previous grain-crops; while to permanent mowing-fields, that are associated with land under tillage, manure is neither applied so frequently nor so heavily as to the arable parts of the farm.

In some parts of North Germany, remarkable success has not infrequently attended the application of kainit, or another of the cheaper kinds of Stassfurt salts, to lupines on poor, sandy soils, which of themselves were no longer able to yield crops of this plant; and several writers have been led to urge that, contrary to what is true of most other crops, potash salts, by themselves, are often a sufficient manuring for lupines. It is remarkable, at all events, that in many instances excellent crops of lupines have been obtained by means of potassic fertilizers alone in cases where neither phosphatic nor nitrogenous fertilizers did any good, either by themselves or when used as additions to the potash. Specially good results have been obtained on applying potash-salts, for lupines, to sandy soils which have been marled, even in localities where the lupine is apt to fail on such land unless potash has been applied to it. It is said, however, of this marled land, that the kainit should be put upon it in the autumn, and that it is apt to do harm when applied in the spring.

The Crops best suited by Potash.

Where sugar-beets are cultivated for sale, or chicory roots to be used as a substitute for coffee, or potatoes, or tobacco, large quantities of potash are carried off from the land, and the economy of employing special potassic fertilizers to make good the loss has often been strikingly manifested. From numerous field experiments made in England, with potatoes, Voelcker was led to conclude that "potash-salts are useful and very desirable constituents in a potato-manure, especially if it is intended to be applied to light land." He obtained highly satisfactory crops of potatoes on light soils by means of mixtures of kainit and superphosphates. Good crops of potatoes were sometimes obtained by means of potash salts alone, "though they are by no means the most desirable manure for potatoes." In experiments on mangolds, Voelcker found that crude potash salts gave a considerable increase of crop, though sometimes this increase was no larger than that got by means of common salt. Mixtures of potash salts and superphosphate, on the other hand, sometimes did as good service as farmyard-manure. They gave a very large increase over the unmanured land, and considerably more than was obtained by means of mixtures of superphosphate and common salt. On Swedish turnips growing in light land, crude potash salts had a very good effect, both when used by themselves or in conjunction with a superphosphate, though it was noticed, sometimes, that the superphosphate tended to increase the growth of the turnip-tops unduly. "On the whole," Voelcker found "that the application of crude potash-salts, in conjunction with superphosphate, materially benefits root-crops grown on light and poor soils." Several instances are on record, moreover, where dressings of sulphate of potash have brought abundant and healthy crops of sugar-beets on land where beets had previously failed, and which was supposed to be exhausted in respect to this crop.

In Germany, where the use of potash salts as manure has lately been largely extended, they are particularly commended for beets, potatoes, clover, cabbages, tobacco, buckwheat, hops, grapevines, flax and oats. Here in New England, they have always been esteemed for Indian corn and (formerly) for potatoes. But it is upon clover especially, and other leguminous plants, that potassic manures show the most remarkable effects. The old notion of farmers, that, by applying wood-ashes to grass-land, they can "bring in" clover, is a case in point, which consists perfectly well with the results of methodical experiments. In trials made upon a variety of plants, and continued through long terms of years, Lawes and Gilbert found that potassic manures were more useful with clover, beans and peas, than with any other plants; though, as regards grain-crops, it was noticed that potash was somewhat more useful for wheat than it was for barley.

This experience has been summed up by Gilbert in the following terms. It is found, he says, that easily assimilable nitrogenous manures have generally a very striking effect in increasing the growth of grain-crops, such as wheat, barley and oats; although these grain-crops contain comparatively little nitrogen, and take but little of it from the land. The leguminous crops, on the other hand, such as peas, beans, clover, and others, although highly nitrogenized, are by no means characteristically benefited by the use of direct nitrogenous manures, such as ammonia salts and nitrates, though nitrates act much more favorably than ammonia salts. It appears, indeed, that we may say, Use phosphates for turnips, potash for leguminous plants, and active nitrogen for grain. "By these experiments, we have learned the extraordinary effect of phosphates upon turnips, and the comparative indifference of mangolds to this manure." (Warington.)

As was just now said, wood-ashes have long been esteemed in this country as a manure for potatoes, though some observers have maintained that they are apt to favor the growth of the fungus which causes "scab," an opinion which has been verified by the researches of Wheeler, who has shown that, although the potash in the ashes may not be harmful, all fertilizers which, like ashes, contain carbonate of lime, are decidedly favorable for the production of scabby potatoes.

In Europe, the significance of potash salts for the growth of potatoes has repeatedly been noticed. In the words of Dyer, the potato — which is a crop apt to suffer either from over-manuring or under-manuring — is often so particularly grateful for potash that it is worth the while, on almost any soil, to try the effect of this fertilizer. He recommends that, on calcareous soils which have been well dunged, 2 or 3 cwt. of superphosphate, together with 3 or 4 cwt. of kainit, should be applied before or immediately after the sets are planted, and that 1 cwt. of nitrate of soda should be subsequently strewn as a top-dressing — best in two instalments. Or, if only a moderate quantity of dung has been applied, twice as much of the nitrate of soda may be used. On land deficient in lime, he would use, instead of the superphosphate, 2 or 3 cwt. of plain Peruvian guano, or of fine bone-meal, or 5 or 6 cwt. of phosphatic slag. On sour or peaty land, a few more cwt. of the slag might be used with advantage.

Instances of Income and Outgo of Potash.

Heiden has given the following statement in illustration of this matter. Every hundredweight of sugar-beets taken from a field carries away, on the average, 0.359 lb. of potash; but since a Morgen (= 0.631 acre) of land yields from 140 to 200 cwt. of the beets, it thereby loses from 50 to 72 lb. of potash, no account being taken of the potash in the beet-leaves which are left upon the land. Hence, wherever beets are grown year after year for sale, as is done not infrequently in some parts of Central Europe, there will manifestly soon be need of dressing the land with some kind of a potash compound.

Karmrodt has given the following computation of the yearly outgo and income of potash on an estate of 1,717 Morgen, that had neither water-meadow nor pasture to support its cattle, and which had for years been devoted to the growing of sugar-beets: —

Yearly export of potash: —	
In the crops	103,812 lb.
In products from cattle	473 "
Total export of potash	104,285 "
Amount of potash added to the land: —	
In form of guano and night-soil	8,439 "
In the seeds planted	1,021 "
In the dung of cattle: —	
As obtained from food grown on the estate	74,875 "
As obtained from hay and oil-cake bought	4,967 "
Total potash added to the soil	87,302 "

Hence the excess of potash removed each year was equal to 16,983 lb., or as much as would be contained in 14,615 cwt. of hay. It appears from this statement, as well as from the calculation of income and outgo of potash which was given under the head of Farmyard-manure, that there is little risk of exhausting any field of potash so long as the land is adequately manured with the dung of cattle that are supported on hay from water-meadows (or bog-meadows or salt-marshes), and on straw and clover. Several calculations as to the income and outgo of potash on farms thus conducted have been given by Heiden in his "Düngerlehre." His figures show emphatically that, far from losing potash, many European farms continually become richer and richer in this constituent. In consequence of this tendency, no money profit can be expected from the application of special potassic manures, considered merely as sources of this particular form of plant-food, upon farms that have long been kept in good heart by means of abundant dressings of farmyard-manure. But wherever forage crops, or even straw, are sold off a farm in undue proportion, or where large quantities of beets, carrots, cabbages, turnips, onions, potatoes or tobacco are sold year after year, the judicious use of potash salts may be expected to more than repay the cost of them.

In cases where milk is sold off a farm, it commonly happens that more or less fodder (corn-meal, shorts, cotton-seed-meal, or the like) is bought to reinforce the hay on which the animals are fed, and that in this way more potash is brought to the farm than goes off in the milk, not to speak of the rough fodder, or of the potash in that fodder, which in New England comes to the arable part of many farms from browse, wild pastures and bog-meadows.

Before the discovery of the mine of potash compounds at Stassfurt in Germany, about the middle of this century, it was a very difficult matter for those farmers who had no access to wood-ashes to procure special potassic fertilizers to meet the wants of particular crops, such as those just now mentioned, and the wholesale cultivation of them was consequently less easy than it is now.

Potashes obtained from various Plants.

A glance at the proportion of potash obtainable from various plants in the manufacture of potashes upon the large scale, will show at once that some plants, or rather some parts of plants, contain much more of it than others. One thousand pounds of old spruce wood yield 0.5 lb. of potashes; of old poplar wood, 0.75 lb.; of old oak wood, 1.5 lb.; of corn-stalks, 17.5 lb.; of bean-stalks, or sunflower stalks, 20 lb.; of grape-vine twigs, 40 lb.

As a rule, potash pushes forward into the extremities of plants, i. e. into the twigs and new leaves. It will be noticed how well worth saving for the compost-heap the grape-vine clippings must be, and the remark is as true of the shoots and twigs of almost any other bush or tree. It has long been familiarly known that grape-vine twigs are thus rich in potash, and it is a fact of daily observation in wine countries, that considerable quantities of bitartrate of potash are obtained from the argol or tartar which is deposited in the wine-casks after the grape-juice has fermented. Hence a popular impression arose, and still persists, to the effect that grape-vines are specially liable to exhaust the soil of potash. This notion is untrue. It was disproved by Boussingault as long ago as 1850; for having analyzed all the products that are carried away from a vineyard, and compared the amounts of potash in these products with the amounts of this substance carried off the land in other crops, he found that the grape-vine could not be regarded as a plant standing in special need of potash.

He states that, in the locality in question (Alsatia), there is carried off from a hectare (= 2½ acres) of land by a crop of

	Alkalies. Kilos.	Phosph. Acid. Kilos.
Potatoes	63	14
Beet-roots	90	12
Wheat, with its straw	27	19
Wine, including clippings from the vines, and the marc or residuum left in the wine-press	17	7½

None the less it may be well on some soils, as Dehérain has remarked, to apply potassic fertilizers to vineyards, especially in localities where — as at the South of France — the vines are habitually dressed, not with farmyard-manure, but with oil-cake and with woollen rags.

It is to be observed that figures like those just now given, which have been made in the interest of the potash-boiler, do not necessarily give the true agricultural value of the ashes of the several plants enumerated. For example, the ashes from any plant rich in silica, like the various grasses and grain-bearing plants, would contain much silicate of potash which is not readily soluble in water. Such ashes might yield only a comparatively small amount of potashes when treated with water in the leaching-tubs, although they are really very valuable as a fertilizer.

In some parts of Europe, straw and weeds were formerly burned for the manufacture of potashes, and the idea was several times thrown out that it might be well in those districts to favor the growth of plants specially rich in potash. Hermbstädt long ago tried the plan of planting wormwood, which grows upon very poor soil, for the production of potashes. He found, by experiment, that one Magdeburg acre (18,000 square feet) would yield three crops a year, or some 20,000 lb. of dry plant, 2,000 lb. or more of ashes, and 900 lb. of potashes; or 12 % of ash, and about 5 % of potashes. Beichos proposed to grow tansy for the same purpose, and stated that an acre of this plant will yield 1,250 lb. of potashes. Fresenius proposed the common marigold of Europe (Chrysanthemum segetum) as a potash-producing plant. It grows wild in enormous quantities in certain districts, and the ash contains about 25 % of potash.

Stems and Stalks of Tobacco.

Tobacco-stalks, from which the leaves have been stripped, are known to have considerable fertilizing power, and are consequently often returned to the land. S. W. Johnson reports that the anhydrous stalks of tobacco-plants contain nearly 5 % of potash,

$\frac{7}{10}$ of a per cent of phosphoric acid, and nearly 3½ % of nitrogen, of which $\frac{2}{10}$ of a per cent is in the form of nitrates. At the time when the leaves are stripped from them, the stalks are thought to contain usually some 46 % of water. Hence, when in that condition, 100 lb. of the stalks would contain 2.6 lb. of potash, 0.36 lb. of phosphoric acid, and 1.85 lb. of nitrogen. From 1,500 to 2,000 lb. of the dry stalks, containing $15 to $20 worth of fertilizers, may be yielded by an acre of land. Another sample of tobacco-stalks examined by Johnson contained when cured 67 % of water, 3 % of ashes, and 0.7 % of nitrogen. The ashes contained 1.37 % of potash, and 0.18 % of phosphoric acid.

Tobacco-stems also, i. e. the midribs of the leaves as rejected by manufacturers of cigars, have considerable repute as a fertilizer. Johnson reports, in one sample that was purchased in New York City, 33 % of water, 5¼ % of potash, ½ a per cent of phosphoric acid, and nearly 2 % of nitrogen. In another sample, believed to be somewhat damaged, he reports 46.7 % water, 6.25 % potash, 0.4 % phosphoric acid, and 1.6 % of nitrogen. In a specimen of fine tobacco-dust, sifted from tobacco-clippings, he reports 9.6 % water, 2.8 % potash, 0.5 % phosphoric acid, and 2.4 % nitrogen. The sample of stalks examined, and the dust also, contained a considerable amount of chlorides, say ½ % of chlorine, while the stems, from totally different fields, contained a much smaller proportion. Lime was present in the samples in considerable quantity. Another analysis reported by Johnson, apparently of a better sample of tobacco-stems, gave 19.83 % of water, 7.66 % of potash, 0.75 % of phosphoric acid, 4.26 % of lime, and 1.96 % of nitrogen.

Dietrich's analysis of midribs from the Palatinate gave an average of 22 % ashes, 15 % moisture, 8 % potash, 2 % phosphoric acid, and 2 % nitrogen, of whicn last almost a quarter was in the form of a nitrate.

In some parts of Connecticut, tobacco-stems are largely used, especially for manuring tobacco and early potatoes. For tobacco, they are applied year after year to the same land, sometimes to the extent of 12 tons to the acre, with the result that the crop bears very fine leaves of excellent quality. Sometimes dressings of half tobacco-stems and half stable-manure are applied, though many farmers use the stems without any other manure, unless it be some artificial fertilizer to give the young plants a start.

Potatoes that have been manured with tobacco-stems are said to be exceptionally smooth and fair; and it is thought that where the stems have been used the land is left in excellent condition for other crops.

Barilla from Strand Plants.

Until a time early in the present century, large quantities of fused ashes of peculiar character, called barilla, which contained much carbonate of soda as well as some carbonate of potash, were prepared by burning certain strand plants, notably those of the genus Salsola (saltwort). Much barilla was sent into commerce from Sicily and from the east coast of Spain, where the plants that produce it were regularly cultivated, mown, and dried like hay, and then burned in pits. In the vicinity of Carthagena, for example, where the ordinary rotation of crops was wheat, barley, and fallow, the barilla-plants were often sown on the fallow field. So, too, in case the wheat-crop failed from want of rain, the wheat-land also was sown for a crop of barilla.

This old practice is not a little interesting, in that it goes to show that farmers in saline districts — and in regions which had been "over-irrigated" — formerly possessed one means of improving their land by removing salts from it, which can no longer profitably be practised now that carbonate of soda is made more cheaply from common salt than it can possibly be got from plants. Goebel found in ashes obtained by burning saltwort plants, from the vicinity of the Caspian Sea, 5 % of potash that was soluble in water, and 30 % of soda.

Kinds of Potassic Manures.

Potash is employed as a manure in the form of wood-ashes; the ashes of cotton-seed hulls; as sulphate of potash and chloride of potassium; and as "potashes," which in this country is usually a mixture of hydrate of potash and carbonate of potash.

Mayer's analyses of New York potashes gave, in per cent, —

	"Best."	First Quality.	Second Quality.	Third Quality.
Carbonate of potash (K_2CO_3) . .	44 to 25	56	15 to 53	38
Hydrate of potash (KHO)	50 to 44	6	39 to 5	. .

American potashes are prepared by placing wood-ashes in tubs above a layer of caustic lime, leaching with water, evaporating the lye to dryness, and igniting the residue.

In addition to the above mentioned substances there is the greensand of New Jersey, which is celebrated in its locality as a potassic (and phosphatic) fertilizer; and a few farmers are so situated that they can obtain useful waste products from manufacturing establishments, such as the slurry of the glass-makers, which is an impure sulphate of potash, obtained incidentally in the purification of pearlash; saltpetre-waste from gunpowder mills, and prussiate residues from chemical works where prussiate of potash is made.

Wood-Ashes as a Manure.

Most farmers in New England are agreed as to the high value of wood-ashes, considered as a manure. So firm is their faith in this regard that many persons have drawn from it the false inference that potash is not only the chief thing, but the sole thing, needful to fertilize the land and to bring up those sections of the country which have been run out by careless cropping. The power of ashes to improve the inert nitrogen of the soil has already been mentioned, and it may here be added that this action has often been noticed in Europe on drained moor-land, where wood-ashes do excellent service both by neutralizing the acidity of the sour humus and by causing the earth to ferment. It is hardly fair, however, to class wood-ashes as an exclusively potassic manure, for beside potash, the ashes contain one or two per cent of phosphoric acid, and various other ingredients which are of value to plants; notably a little magnesia and a great deal of carbonate of lime. The importance of these incidental constituents is made plain by the esteem in which leached ashes are held by our farmers, although from the leached ashes all but a very small proportion of the original potash has been washed out.

Leached ashes consist for the most part of carbonate of lime. Ordinarily they contain no more than from $\frac{1}{3}$ to $\frac{1}{2}$ of one per cent of real potash, and but little more than one per cent of phosphoric acid. Some kinds of peat-ashes contain potash enough to be worth considering, but they are rare. The ashes of coal contain a trace of potash, but not much, if any, more than ordinary loam or than many kinds of sand. Whatever merit pure coal-ashes may really possess must depend upon their mechanical condition, which fits them to do good on clay soils and on soils rich in humus, such as those of reclaimed bogs.

A favorite way of applying wood-ashes is as a top-dressing to grass-land and to pastures, where, by encouraging the growth of clover and some of the better kinds of grasses, they do good service in crowding out inferior kinds of grasses, and in destroying weeds and moss. Some European observers have remarked that wood-ashes may do particularly good service on sour meadows where sedges (carex) might be apt to grow. Wood-ashes are esteemed also for potatoes, on land free from the scab fungus, and for corn and roots, and they are used in the preparation of composts, as has been said, and there is room probably for their greatly extended use in this particular way.

Price of Wood-Ashes.

Until a comparatively recent period, wood-ashes were really almost the only commercial fertilizer that was procurable in this country, and the price of 12½ cents per bushel, at which they were formerly bought and sold, had come to be a sort of standard of value which withstood many vicissitudes. But, for the region around Boston at least, there came a time when ashes were hardly to be had at any price. From 1850 to 1870, for example, they could hardly be looked upon in the light of a commercial manure in this vicinity. Even leached ashes were at that time sold at 25 cents the bushel on the seaboard, and fresh ashes were not to be had.

Latterly, thanks to the great diminution in price of all kinds of potash compounds which has resulted from the development of the potash industry at Stassfurt, wood-ashes are brought into New England by rail from the less settled part of the country, notably from Canada, and they can be ordered from Oswego or Montreal by the car-load nowadays at tolerably reasonable rates. According to S. W. Johnson, "Unleached Canada ashes of average quality contain 5.7 % of potash and 1.2 % of phosphoric acid. Ashes made largely from our hard woods are somewhat richer both in phosphoric acid and potash. . . They vary a good deal in composition, and some samples are notably deficient in potash." Occasionally they are debased by admixtures of coal-ashes and often by mere dirt. Probably, leached ashes are sometimes mixed with them.

It may be said, in passing, that the price of 25 cents the bushel for leached ashes, as just now given, was much higher than such ashes are really worth. Fresh ashes, on the contrary, may in some cases be worth more than 25 cents per bushel, as has been set forth in detail in one of the numbers of the Bulletin of the Bussey Institution.

Of course the value of ashes may vary considerably according to their source, though practically this variation is less than would be supposed at first sight. Ashes are richer or poorer in potash and other useful ingredients according to the kinds of plants from which they have been derived and to the soil upon which the plants grew. And particularly according to the parts of the plant that have been burned. The ashes of twigs (fagots for example) would always be worth much more for agricultural purposes than the ashes of heart-wood taken from the middle of an old tree; and, in general, the smaller and younger the wood burned, the better would be the ashes. Practically most fires are fed with cord-wood that has been cut under very much the same conditions of growth almost everywhere. So that in places and cases where no coal is burned, the variations in composition of ashes taken from domestic fires are, comparatively speaking, small. To judge from the books, taking what is known of the composition of the ashes from young twigs and that from heart-wood, one would say that the proportion of potash in ashes might vary from 5 to 20 %. But a much better criterion of the real composition of ashes was afforded formerly by the experience of potash-makers in this country, according to which a bushel of "house ashes" weighed about 48 lb. on the average, and yielded rather more than 4 lb. of potashes.

I have myself investigated this question somewhat in detail, and have found by the analysis of a number of samples of house-ashes that selected samples may contain on the average about 8.5 % of real potash and 2 % of phosphoric acid; or say 4.25 pounds of potash and 1 pound of phosphoric acid per bushel. Hence there is enough potash and phosphoric acid to make the bushel of ashes worth 20 or 25 cents, and, beside that, some 10 or 15 cents additional may be allowed for the "alkali power" of the ashes, i. e. the force of alkalinity which enables the ashes to rot weeds and to ferment peat. The notion that the ashes from soft woods, such as pine and poplar, are worthless, is an error. The soft woods yield comparatively little ashes, and the ashes are so light that they may readily be blown away by the wind; but weight for weight, the ashes from soft woods appear to be as good for agricultural purposes, or very nearly as good, as those from hard woods. It is important, however, in buying ashes, to assure one's self that they have neither been contaminated with coal-ashes nor adulterated with leached ashes.

Alkaline Lyes make Soils adhere.

One peculiarity which ashes owe to their alkaline quality is worthy of special attention, since it must often exert a very decided influence upon the capillary power of the soils to which the ashes are applied. It is a well-established fact that alkaline lyes, when added to clay or loam, make these materials more plastic and adhesive than simple water can. If a solution of either of the alkalies, or of an alkaline carbonate, viz. carbonate of potash, such as is got by leaching wood-ashes, or carbonate of soda, or carbonate of ammonia, is poured upon a small quantity of loam, the latter will be made muddier and more sticky than it would be if it were moistened with mere water.

According to M. Whitney, the alkaline solutions seem to loosen the attachment of the particles of clay in the soil for the particles of sand, and to float off the clay particles to fill up the spaces between the sand grains which had previously been open. As a result of this clogging of the pores, the circulation of water in the soil is very much retarded. In one experiment, where an inch of water passed through a column of soil in about 25 minutes, six or eight hours' time were required after the soil had been wet with ammonia.

That this action of the alkalies may sometimes be of great practical importance is attested by the fact observed by Whitney, that soils are sometimes met with in which the particles of clay are held so closely to the grains of sand that the soil has the appearance and the properties of a sandy soil, although it actually contains as much clay as there is in many distinctively "clay lands."

It has long been known that carbonate of potash and carbonate of soda tend to keep clay in a "puddled" or "tamped" condition, as the terms are. A ball of moist clay or loam thus charged with an alkaline carbonate does not tend to crumble or fall to powder during the process of drying; but remains a hard lump. A tenacious, fire-proof cement for stopping holes in stoves and stove-pipes is made by mixing powdery clay with fine wood-ashes, and working the mixture with water to a smooth paste, which is applied as such, and becomes hard on drying.

Alkali-soils.

It is because of this peculiarity of the alkalies that it often becomes impracticable to till soils when any large proportion of carbonate of soda is contained in them; that is to say, such "alkali soils" cannot be tilled economically by the ordinary mechanical appliances of the farm. No matter how often such a soil is ploughed or harrowed, it will always remain a mere mass of hard clods, unless, indeed, it is muddy. Such a soil cannot be brought to a condition of good tilth by mere ploughing, unless the alkali be washed out of it by drainage and irrigation, or unless it is neutralized, as Hilgard has suggested, by means of gypsum: —

$$Na_2CO_3 + CaSO_4 = CaCO_3 + Na_2SO_4.$$

Unless the alkali be removed or decomposed, such soils cannot be made mellow, simply because the alkali causes the particles of earth to stick together. The earth can be torn asunder into lumps (clods) by the ploughshare, but the furrows will not fall down to powder on drying, which is the essential feature of good tillage.

These alkali soils have given much trouble in California in recent years. As Hilgard has remarked, the presence of no more than 0.1 % of carbonate of soda in a clayey soil may be sufficient to render the soil practically untillable, even when considerable quantities of neutral salts of sodium and calcium are also present. But it may well be asked whether, in many cases, the difficulty does not arise from the presence of too much of a good thing. It seems plain, on the face of the matter, that the tilth of many a porous open soil might be improved by means of alkalies acting to make the particles of earth less granular and more plastic, so that capillary water may be lifted more freely and retained more forcibly. It was for the sake of correcting undue looseness that the Norfolk County farmers laid such stress on having their light soils trampled down firmly by means of cattle and sheep that were fed upon the land, and that the Scotch long since resorted to the use of heavy rollers upon their light lands. It is not improbable that the excellent results obtained sometimes by applying potassic fertilizers to the light Norfolk soils, may really have depended upon the impaction of the land by force of alkalinity.

I have in fact found, by experiment upon light land, that this very advantage was obtained by the application of wood-ashes to the soil. A plot of land dressed during several years with what any farmer would have considered a large quantity of wood-ashes became so firmly bound that a yoke of heavy oxen had some difficulty in dragging a plough through the soil in dry summer weather. The furrow where it crossed this plot was a mere mass of clods. Yet through all the years of the experiment, that plot had manifestly been better supplied with water than any of the adjacent plots.

A suggestion thrown out by Sachsse and Becker may here be mentioned as possibly having some bearing upon the case in hand. Their thought was that the continued action of a fixed alkaline carbonate upon silicates in the soil might produce enough of a colloid alkaline silicate to bind together fine particles of soil and to hinder flocculation. The force of the suggestion is weakened by the experiments of Milton Whitney, who finds that the capillary condition of certain soils may be very much improved by adding ammonia water (or some other alkali), which simply acts to undo the flocculated condition of the clay which the soil contains, and can hardly be supposed to conduce to the formation of a colloid silicate.

Action of Potashes on Soil-nitrogen.

An objection is sometimes made to wood-ashes, as a manure for tobacco, that the plants grow coarse, perhaps because of nitrogen supplied to the crop by the action of potash on humus; such action, namely, as was discussed under Alkali Composts. The question has even been asked, sometimes, whether the beneficial action of alkalies as manures for leguminous crops may not perhaps depend upon the power of alkaline matters to dissolve organic matters in the soil; or it may be that the increased power of the soil to hold water, due to the presence of the alkali, is unfavorable for the best habit of growth. According to M. Whitney, "The most important factor which determines the texture and color of the leaf is the texture of the soil and its relation to moisture and heat."

The tendency of potashes to promote rank growth is often strikingly illustrated in countries recently cleared of wood. Whereever a heap of logs has been burned, it is noticed that vegetation is apt to be particularly rank and luxuriant precisely where the largest quantities of ashes are lying. Several writers have expressed surprise that these appearances should be as they are, for their first thought was that so large an amount of ashes must destroy vegetation. It is noticed that wheat or other grain sown upon the newly-burned land often "lodges" at those spots where heaps of logs have been consumed. This rankness of growth is probably to be attributed both to a superabundant supply of nitrogenous food, and also to the fact that the spots charged with alkali are in many cases better supplied with moisture than the remainder of the field.

It was noticed long ago by Lorain, that the ground where the log-heaps were burned seemed to be moister than the surrounding soil. All this consists, moreover, with what Hilgard has noticed upon the alkali soils of California, where the alkali "puddles" the clay in the soil, and prevents water from draining away from it. As he puts it, "Soils impregnated with alkaline carbonates may generally be recognized by their extreme compactness and refractoriness under tillage, and by the fact that they are apt to form 'low spots' in the general surface of non-alkaline land, i. e. places where turbid clay-water, dark with dissolved humus, will lie for weeks after the higher land appears dry." . . . "By adding gypsum to such soils, their alkalinity may be destroyed and the dissolved humus will be precipitated and given back to the soil."

Ashes of Cotton-seed Hulls.

There is a variety of ashes procurable in commerce, derived from the hulls of cotton-seeds, as obtained in the process of "decortication" which precedes the grinding and pressing by means of which oil is extracted from the seeds. The hulls, though sometimes used as food for cattle, are often burned as fuel at the oil-factories, in conjunction with wood or coal, whence it happens that the ashes vary considerably in composition. They are naturally more or less valuable, according as they contain less or more of the ash of the supplementary fuel. According to S. W. Johnson, those lightest in color are usually richest in potash.

As brought to the North, cotton-hull-ashes commonly contain from 18 to 30% of potash, chiefly soluble in water, and free from any contamination with chlorides; and from 5 to 10 % of phosphoric acid, of which from 1½ to 2 % is soluble in water. It appears therefore, that, considered as a fertilizer, cotton-hull-ashes are much more concentrated than ordinary wood-ashes. In point of fact, they contain so large a proportion of carbonate of potash that they might do no little harm to crops if they were to be applied injudiciously or in too large quantities. Indeed the very fact of their strong alkalinity makes the hull-ashes so useful for a variety of technical purposes, that it is highly probable that they will not long continue to be available as a manure. Although the supply is limited, the price at which cotton-hull-ashes have been sold hitherto ($35 to $40 the ton in New England) is so low that they have been by far the cheapest source of potash in the market. They have been used with advantage for manuring tobacco, and are specially prized by tobacco growers. The only objection to the use of these ashes is their liability to vary widely as to their composition. Without an analysis there can be no certainty as to the true value of any given sample.

Double Carbonate of Potash and Magnesia.

A hydrous carbonate of potash and magnesia prepared in Germany, would seem to be well adapted for use on soils and crops which are known to profit from applications of wood-ashes or cotton-hull-ashes. According to S. W. Johnson, this substance contains 18 % of real potash and 19 % of magnesia; both of these substances being combined with carbonic acid and water. It is practically free from chlorine. It is to be noted, however, that it contains 5 or 6 % less potash than is contained in cotton-hull-ashes on the average.

Lime-kiln Ashes.

There is yet another product, called lime-kiln ashes, which is sent out by the car-load from Vermont and other localities where lime-kilns are fired with wood. But these ashes consist chiefly of lime-dust. They usually contain less than 2 % of potash, and less than 1 % of phosphoric acid. They may be regarded as wood-ashes admixed and diluted with from 4 to 6 times their weight of lime, much of which has become partially air-slaked. Of course, where the lime-kilns are fired in part with coal, the ashes would be still poorer in potash and phosphoric acid. One special objection to lime-kiln ashes is their liability to contain fragments of limestone which have not been thoroughly burned, as well as pieces of lime which have been superheated or "overburned" as the term is. When too strongly heated in the kiln, lime is left in the form of hard lumps, which do not readily fall to powder on being wet. I have heard the objection from a man who farms a rich bottom land in the western part of Massachusetts, — and who can hardly have been familiarly acquainted with the gravelly drift soils of the upland, — that "there are hard lumps of lime in such ashes which will take the edge off a hoe quicker than thought."

Brick-kiln Ashes.

In a sample of ashes from a brick-kiln that had been fired with chestnut-wood, Professor Johnson reports 1.5 % of potash, and less than 1 % of phosphoric acid. The sample consisted chiefly of brick-dust and sand. Such ashes as these could be used with advantage on many soils in the immediate vicinity of the kiln; but they are not worth enough to be carried to a distance. So, too, in respect to the lime-kiln ashes, there are doubtless special cases and places where they might be employed with profit by intelligent farmers, although they are not to be compared with wood-ashes, and have no such general applicability as the latter. Generally speaking, they are not to be commended, for they are of variable and uncertain composition, and are never valuable enough to bear the cost of distant transportation. Even as regards the lime in them, they must be decidedly inferior in every way to good quicklime such as is made expressly for the use of farmers or builders.

Greensand.

The greensand, or so-called "greensand marl," of New Jersey, has hitherto been considered as of only local importance, though it contains a good deal of potash, and has been used with great advantage in the regions where it is found. According to G. H. Cook, the potash may be taken on the average as 5 % of the whole weight of the sand; and since a bushel of this substance weighs about 80 lb., it would contain 4 lb. of potash, or about as much as is contained in a bushel of good wood-ashes. The greensand moreover often contains as much as 1 or 2 % of phosphoric acid, though, as a matter of course, both these constituents are in a very different condition from those found in ashes.

Considered as a manure, the greensand acts rather slowly. It is said, for instance, that its effects will be perceived upon land for ten or twelve years. It is evident enough that, so far as its contents of potash and phosphoric acid are concerned, it could not repay the cost of transportation to any very great distance.

Greensand analogous to the fixing Silicates.

Most writers who have discussed the subject hitherto have been disposed to make the objection that the greensand is a sand merely, and neither a manure proper, nor a soil, nor a disintegrated mineral, such as would contain food immediately available for the plant. But, in point of fact, the greensand is a hydrated silicate of iron and potash. It belongs to the mineral species glauconite, and is probably — one might almost say doubtless — competent to act as an agent for absorbing lime, soda, ammonia, and the like, from the soil-water, and at the same time yielding up its potash for the use of plants. If this view be correct, the greensand deserves to receive far closer attention than has been accorded to it hitherto.

Before potassic fertilizers were as abundant as they are now, it might have been questioned whether it would not perhaps be well in some localities to prepare artificially a hydrated silicate of potash and alumina to be applied to light, hungry soils in order to provide a permanent store of potash from which plant-food should be given up slowly through the action of saline matters in the soil-water. But in the greensand the desired double silicate is found ready made. The rock palagonite, previously mentioned, is another natural product whose action upon certain soils would be well worth studying as a scientific experiment.

An instance of the natural fertilization of land by means of a disintegrated volcanic rock has been described by Rozet, and by other French writers. The old district of Limagne, in Auvergne, is an extensive valley bounded at the west and southwest by volcanic hills, from which the prevailing winds sweep off such large quantities of fine volcanic ashes that — on looking down upon the valley from the peaks of the hills — the land is often seen to be shrouded by a faint cloud of ashes, as it would be by a thin mist. These ashes are deposited upon the valley land to its great benefit. It has been computed indeed that as much as 1,000 kilos. of the ashes may be brought to each hectare of land in a single year, and it has been argued that the proverbial fertility of the valley may depend in good part upon the constant supplies of plant-food which are brought to it in the ashes.

State of the Potash in Soils.

It is to be remarked that most of the potash immediately available for crops which is contained in ordinary soils probably occurs there either in the form of hydrated double silicates or in that of double humates, though in really good soils, or in those recently manured, some small portions of soluble potash salts may be found clinging to the earth by mere adhesion. A part of the "fixed" potash is doubtless dissolved by mere water, and brought to the plant as an aqueous solution, and some of it is probably dissolved out by carbonic-acid water (i. e. bi-carbonate of lime), and so carried to the plant in the form of potassium bi-carbonate, while still another portion may be dissolved out directly from the soil by the action of acids exuded by plant-roots. Each of these agents would naturally dissolve some potash from mere gravel, or from crumbled or broken rocks, but it is to be supposed that their solvent action is of paramount importance when exerted upon the hydrated silicates and the humates.

Dyer has obtained some instructive results on testing how much potash can be dissolved out from soils by dilute citric acid (containing 1 % of the crystallized acid) and by hydrochloric acid, respectively, according as the land has or has not been manured. Thus, on 8 fields which had been dressed with sulphate of potash for many consecutive years, he found that the quantity of potash soluble in hydrochloric acid exceeded the amount dissolved thereby from unmanured land in the proportion 1.36 : 1, while the quantities of potash soluble in dilute citric acid in the two cases were as 9 : 1. A field which had been dressed continuously with farmyard-manure during 38 years, gave up twice as much potash to the dilute citric acid as another field did, which had been left unmanured during 18 years, after having received farmyard-manure annually during the previous 20 years; and it was noted that the crops obtained from the land differed in the same proportion as the amount of soluble potash differed.

Much more potash soluble in citric acid was found in land which had been dressed with the sulphates of potash, soda and magnesia, without any addition of superphosphate, than could be dissolved out from land which had received some superphosphate of lime as well as the sulphates above mentioned, because the land which got the superphosphate yielded much larger crops than the other land, and these crops carried off much of the soluble potash. Similar results were obtained also on land dressed with rape-cake, together with the sulphates, with and without addition of the superphosphate. It was noticeable, furthermore, that land dressed with ammonium salts, without any addition of potassic fertilizers, yielded very little potash to the weak citric acid; whereas, in case nitrate of soda was applied to the land, without any potassic fertilizer, a considerable amount of the comparatively inert potash in the soil was loosened up so that it dissolved in the citric acid. Dyer suggests that any soil which yields less than 0.005 % of potash to citric acid of one per cent probably stands in need of a potassic fertilizer.

Potash from Rocks.

It has often been proposed formerly to obtain potash for agricultural purposes by decomposing feldspar and other potassic rocks artificially by means of chemical agents. For example, H. Wurtz, of New York, proposed long ago to decompose the New Jersey greensand by fusing it with chloride of calcium; and several persons have thought to obtain soluble potash by fusing or fritting feldspar with lime. Neither of these methods has ever had any economic importance, and since the discovery of a mine of soluble potash compounds at Stassfurt they are likely to be forgotten. No doubt, however, there are many potassic rocks, such as the greensand, and the palagonite, and various traps and zeolites, possibly some kinds of feldspar even, or slates, which in some instances might repay the cost of reducing them to powder. Small batteries of stamps driven by water power, such as were formerly used abroad for pulverizing bones in inland agricultural districts, might perhaps be established with profit in certain localities. The experiment is well worth trying, in some localities where greensand can be procured, whether the cost of reducing the sand to fine powder would not be more than repaid by the increased efficiency of the product as a manure. It should be said, however, that Lucas, who experimented in this sense upon a bituminous shale, rich in potash and phosphoric acid, after it had been used as fuel, found an advantage in reducing the mineral to the form of a granular powder rather than to the condition of fine dust.

Generally speaking, the rock had better be roasted before it is powdered. That is to say, it may be heated to low redness and then quenched with water to make it friable. Fuchs showed long ago that when feldspar, and other minerals that contain silicate of potash, are calcined at not too high temperatures, they become comparatively decomposable by chemical agents, and that a part of their potash may be extracted in this way. This behavior of the roasted minerals is similar to that exhibited by roasted clay or by clayey soils that have been pared and burnt, as will be explained in a subsequent chapter. Lampadius found in field experiments where rocks that contained silicate of potash, such as gneiss and granite, and some kinds of porphyry and of trap, were moderately calcined and then applied to the land, that the growth of plants was promoted in a remarkable manner.

The Potash Mine at Stassfurt.

The deposit of potash minerals at Stassfurt, already repeatedly referred to, is one of so much importance that a brief description of it will be in order. The products from this mine will doubtless henceforth control the price of potash compounds everywhere.[1] The deposit in question occurs in connection with a bed of rock-salt of enormous extent, above which, capping it as it were, repose layers of several saline minerals, notably compounds of potassium, magnesium, and lime.

There seems to have been an inland lake or sea, through the evaporation, or rather the boiling down of the waters of which, rock-salt was deposited by crystallization until the mother liquors above the salt became so highly charged with compounds of potassium, magnesium, and calcium, that crystals of these compounds were deposited in their turn on top of the salt.

As long ago as 1839, borings were made at the locality in the hope of finding salt, and brine was actually obtained in 1843; but it was so highly charged with magnesium compounds that it was not worth working. After a while, certain geologists who had studied the locality expressed the opinion that the magnesia must have come from some other source than the bed of rock-salt of whose existence they were convinced, and this view was corroborated by the matter brought up by a new boring, made in 1848 or 1849. It having thus been proved that the magnesia must have come from a bed lying above the pure rock-salt, mining operations were undertaken in 1851 in order to get at the salt. By 1856 two shafts had been sunk to the depth of some 1,100 feet, where a bed of impure rock-salt was struck. This was some distance below the potash mineral, the value of which was then unsuspected.

Pure rock-salt was reached in 1857, as had been anticipated, and its extraction was proceeded with; but it was not until 1859 that the true value of the layer of potash mineral was recognized. The dip of the layers and general character of the deposit having by this time been well made out, a new pit was sunk nearly a mile from the first, by means of which both the potash and the salt can be reached at a less depth and worked to better advantage than before. This new shaft was finished in 1862, and from that time forth enormous quantities of the potash minerals have been extracted. In more recent years, additional shafts have been sunk both in the neighborhood of Stassfurt and at somewhat distant localities, notably at Kalusz.

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[1] Enormous deposits of potash minerals have been found in Austrian Poland also, but they are less favorably situated for commercial purposes than the Stassfurt bed. These distant mines might become important, however, at any moment, in case access to the Stassfurt products were to be hindered by war, or by export duties or other legislative interferences. Meanwhile the mere fact of the existence of the Austrian mines tends to keep the potash trade at Stassfurt free.

The bed of salt beneath the potash minerals is of unknown depth; but, taking the salt in connection with its covering, the entire deposit may be conveniently divided into four principal layers, or beds, each of which is well characterized at the centre by the predominance of minerals peculiar to it, though at the points where the layer touches the layers above and below it the character of its contents is by no means so well defined. The rock-salt at the bottom is wellnigh pure, though interspersed with veins of anhydrous sulphate of lime. Next above is a 100-foot-thick bed of salt, interspersed with veins of a complex sulphate of potash, soda, and magnesia (polyhallite). Above this is a 90-foot bed of sulphate of magnesia (kieserite), mixed with a double chloride of potassium and magnesium. And, finally, at the top is a 70-foot bed of the potash mineral proper (carnallite); this is a hydrated double chloride of potassium and magnesium, containing, when pure, about 27 % of dry chloride of potassium. The mineral is detached in large masses from the bed by means of gunpowder. The cost of extracting it is exceedingly low, and the amount produced is limited only by the demand.

In the beginning, the crude potash mineral was sent into commerce to be sold as a fertilizer under the name Abraum Salt, and it is perhaps still so used to a small extent; but chemical works were soon established for the purpose of purifying the mineral, and several of the products obtained at these works are now used as manures. Both chloride of potassium and sulphate of potash may be had there in varying degrees of purity.

Muriates of Potash.

By subjecting the crude mineral carnallite to processes of solution, crystallization, lixiviation and steaming, there is obtained chloride of potassium of various degrees of purity, and from the chloride other compounds of potash are manufactured, notably sulphate of potash and carbonate of potash. One particular variety of the chloride, known as "muriate of potash of 80 %," usually contains from 80 to 85 % of pure chloride of potassium.

It may be said to contain about half its weight of real potash (K_2O). It has been largely used as a fertilizer, and may perhaps be as good as any other of the Stassfurt products for the generality of purposes. Other varieties of the muriate are prepared which are considerably stronger than the foregoing. Thus, one process of manufacture is said to yield products that contain from 85 to 95 % of pure chloride of potassium; there is another product which is classed as "95 to 98 % muriate"; and still another which contains 98 or 99 % of the pure chloride; but it is probable that neither of these varieties has any special advantage over the 80 % muriate, for agricultural purposes. There is yet another much weaker grade of the muriate obtained as an incidental product, which contains no more than some 45 to 50 % of chloride of potassium.

It is of interest to note that carnallite, as taken from the mine, contains traces of ammonium chloride. Usually no more than 0.01 to 0.08 % of it is present, though occasionally as much as a quarter of one per cent has been detected. But in the preparation of artificial carnallite the proportion of ammonium chloride increases to such an extent that 4 % of it or more may be contained in the final product. It has been noticed indeed, in making chloride of potassium from carnallite, that a deposit sometimes forms which contains 80 to 90 % of the ammonium chloride.

Muriate of potash, no matter what its strength, may answer well enough for clover, grass, corn, and ordinary root-crops, and it has the merit of being cheaper than the sulphate. But it is objectionable in respect to sugar-beets, tobacco, and sometimes as regards potatoes. The chlorine in it hinders beet-sugar from crystallizing, and, in some soils, tends to make potatoes waxy rather than mealy. It impairs the quality of tobacco-leaves to such an extent that they command a lower price than would have been the case if another kind of potash salt had been used. Hence sulphate of potash that contains no contamination of chlorides is greatly preferred for tobacco and beets; and is esteemed to be best, on the whole, for potatoes also, especially in cases where — as is not unusual in Germany — the tubers are to be used for making starch. It should be said, nevertheless, that the chloride is not by any means always harmful in respect to potatoes. Numerous experiments are on record which show that under some conditions potatoes succeed as well with chloride of potassium as with the sulphate, or even better. Some accounts say that if the chloride is put upon the land in the autumn before the potatoes are to be planted, heavy crops of tubers of excellent quality and flavor may be counted on if the season is favorable for growth.

Influence of Chlorides on Soil-water.

One attribute of muriate of potash, which it shares with several other saline fertilizers, is to increase the power of some soils to draw up water from below. As has been stated under the head of nitrate of soda, it has often been observed that applications of nitrates as well as of chlorides and sulphates tend to keep the land moist in dry weather, and M. Whitney has found by experiment that such saline solutions have an appreciably larger lifting-power than mere water has. If the lifting-power of water, due to surface tension, is stated as 7.532, that of a solution of sodium nitrate is 7.730, of a solution of muriate of potash 7.907, of sodium chloride 7.911, and of magnesium chloride 7.964.

It has been noticed in Europe not infrequently, when heavy dressings of saline fertilizers are applied to land which is to all appearance dry, that it suddenly becomes visibly moist, because the saline matter has attracted to itself some of the water in the soil. But when the conditions are favorable for drying off, by way of evaporation, the water thus brought to the surface, a very firm crust is apt to be formed, which in some cases can hardly be broken with the hoe. In order to avoid this difficulty, Maercker recommends that heavy dressings of potash salts should be applied either in the autumn, or at least a month before the time when seeds are to be sown, and that the salt should then be worked into the soil with the plough or the cultivator. In the case of heavy soils, it has been found to be advantageous to apply lime together with the potash salt.

Sulphates of Potash.

Several grades of sulphate of potash are manufactured at Stassfurt, either by processes of decomposing the double sulphate of magnesia and potash (see below), or by heating chloride of potassium with sulphuric acid in a reverberatory furnace and calcining the product. One of the Stassfurt sulphates contains as much as 96 to 98 % of the pure salt, and another, which is sold in considerable quantities in this country under the name, "high grade sulphate of potash," contains 90 to 95 % of the pure sulphate and is guaranteed to hold from 50 to 52 % of real potash (K_2O), and to be practically free from any contamination of chlorides. This material is evidently good enough for agricultural purposes.

Either of these excellent products might easily be prepared in this country by the manufacturers of muriatic acid if they would but operate upon chloride of potassium of high grade instead of using common salt as has been customary. On heating muriate of potash with oil of vitriol in an iron vessel, muriatic acid distils off, while a sulphate of potash remains, but, in order to obtain a fusible residue which can be raked out of the retort without trouble, it is customary to employ rather more oil of vitriol than would be sufficient to change all the muriate of potash to sulphate of potash. Instead of working upon the basis expressed by the equation

$$2\ KCl + H_2O,SO_3 = K_2O,\ SO_3 + 2\ HCl,$$

" an excess " of sulphuric acid is employed, so that there may be formed a certain quantity of " acid sulphate of potash," the mode of formation of which may be indicated by the following equation

$$2\ KCl + 2\ (H_2O,\ SO_3) = (K_2O,\ H_2O,\ 2\ SO_3) + 2\ HCl.$$

Ordinarily, about 1.5 molecules of sulphuric acid are taken for two molecules of chloride of potassium, and a " sesquisulphate of potash " is obtained, and this product must be roasted, after it has been taken from the retort, in order to expel the excess of acid, and obtain real sulphate of potash. The acid sulphate is a corrosive substance wholly unfit to be put upon land that is soon to be seeded or planted, for it would kill speedily seeds and young plants. It might sometimes be used with advantage for killing weeds, insects or worms on land infested with these pests, or it might be composted with weeds to kill their seeds. In case a manufacturer should neglect the roasting process, and a quantity of the acid sulphate should unwittingly fall into a farmer's hands, the acidity might be corrected by means of wood-ashes, either leached or fresh, by phosphatic slag, or by means of bone-black in case the mixture could be left to itself for some time before spreading it.

It is to be noted that the normal, neutral sulphate of potash is not in the least corrosive. It may safely be applied to the land in much larger quantities than are permissible as regards the chloride of potassium. Indeed, it is a general rule that the chlorides of potassium, sodium, calcium and magnesium are much more likely to do harm than the corresponding sulphates. Schuebler showed long ago that, in pot experiments, one part by weight of common salt might do as much harm as 8 to 11 parts of a neutral sulphate of potash, soda or magnesia.

Beside the high-grade sulphate above described, several other Stassfurt sulphates are procurable. For example, there is one with 80 % of pure sulphate of potash, which should carry 40 % or more of real potash, but it contains much chlorine, even to the extent of more than one-third its weight. More than two-thirds of the potash in this compound must be in the form of muriate of potash. Another impure product, improperly classed as sulphate of potash, contains 25 % of real potash, and yet another 10 %.

Kainit.

One of the commonest of potassic fertilizers is a mineral called kainit, which, though seldom seen at the original Stassfurt mine, is found in tolerable abundance at the newer mines in the neighborhood of Stassfurt. Kainit is often spoken of as "sulphate of potash," or as "low-grade sulphate of potash," but these expressions are improper in view of the large proportion of chlorides contained in it. Usually, there is enough chlorine in the kainit of commerce to amount to rather more than one-quarter of its weight. Indeed, there is enough chlorine in it to combine with all the potassium which it contains, and some chemists believe that chloride of potassium, and not sulphate of potash, is really present in the mineral. As imported into this country, kainit is of rather variable composition. Usually it contains from 11 to 15 % of real potash, and it is admixed with various impurities, notably common salt and gypsum. It commonly contains more soda than potash, and rather less magnesia. It is supposed to have been formed from carnallite in places where limited quantities of water have gained access at some time to the latter.

Pure kainit may be regarded either as consisting of sulphate of potash, sulphate of magnesia, and chloride of magnesium (K_2O, SO_3; MgO, SO_3; $Mg\,Cl_2 + 6\,H_2O$); or as composed of sulphate of magnesia and chloride of potassium. At one time the formula of kainit was written $KCl; 2(MgO, SO_3) + 6\,H_2O$, but inasmuch as the mineral deliquesces in the air, as chloride of magnesium does, while neither chloride of potassium nor sulphate of magnesia is deliquescent, the first of the two formulas above given would seem to be more appropriate than the other. When kainit is left for a long time in moist air, a quantity of the magnesium chloride dissolves and drains away from it; and on treating the mineral with alcohol, chloride of magnesium is dissolved. Fleischer has suggested that the tendency of the powdered mineral to "ball" and become lumpy may be avoided by mixing with it 2 or 3 % of dry powdered peat. It is said that some German dealers in fertilizers have adopted this method, and that it has been found to be advantageous. The name kainit has often been applied to a manufactured article as well as to the native mineral.

The cheapness of kainit commends it in many cases, as, for example, when grass-land is to be manured, and enormous quantities have been used both in Germany and in this country. Not infrequently it has given better satisfaction than the 80 % muriate. In Germany it has been noticed occasionally that the application of kainit to oats, at the rate of 2.5 cwt. to the Morgen of land, decidedly checked the ravages of the wire-worm. The kainit was used, however, in conjunction with nitrate of soda and di-phosphate of lime.

Fleischer reports experiments made on moorland near Bremen, where both the yield and the character of the herbage obtained by means of additions of kainit were determined: —

	There was obtained kilos. of fresh grass
From one hectare of meadow, dressed with phosphates alone . .	12,000
From one hectare of meadow, dressed with phosphates and a small quantity of kainit	23,000
From one hectare of meadow, dressed with phosphates and much kainit	41,000

Meanwhile the proportion of clover in the fodder of the first mowing increased from 3 % to 10 % and 27 %, and in the second mowing from 10 % to 20 % and 34 %, and the proportion of wild ("sour") grasses in the crop diminished from 19 % to no more than 3 or 4 %.

Double Sulphate of Potash and Magnesia.

Yet another substance, often sold as "sulphate of potash," is composed of potash, magnesia and sulphuric acid, and is known as double sulphate of potash and magnesia. Sometimes it is called "manure salts." It commonly contains from 48 to 54 % of sulphate of potash, and about a third of its weight of sulphate of magnesia, beside moisture and impurities. It is worthy of much consideration because of its cheapness and its comparative freedom from chlorides. As usually prepared, it is said to carry no more than 2 or 3 % of chlorine. The amount of real potash in it ranges from 26 to 29 %.

Cheaper to transport Muriate than Sulphate.

It is noteworthy that the cost of freight for the potash in the muriate of 80 %, which contains half its weight (i. e. 50 %) of real potash, would be only about one-quarter as much as would have to be expended on the crude sulphate of 20 % real potash, for the molecular weights of the sulphate and the chloride differ appreciably. Thus,

$$\begin{array}{ll} K_2 = 78 & \\ S \;\, = 32 & \\ O_4 = 64 & \\ \hline \quad\;\; 174 & \end{array} \qquad\qquad \begin{array}{l} K \;\; = 39 \\ Cl = 35.5 \\ \hline \quad\;\; 74.5 \end{array}$$

But, having regard to potassium in each case,

$$\frac{78}{174} = \frac{39}{87} = 0.448; \qquad \text{while } \frac{39}{74.5} = 0.523.$$

Beside this advantage in respect to cost of transportation, the potash in the muriate can be sold to the farmer at a lower price than that in the sulphate, because enormous quantities of the muriate exist ready formed in the Stassfurt mine, and can readily be extracted thence at trifling cost, whereas more labor and skill have to be expended in procuring sulphate of potash, even that of no more than tolerable purity.

Manifestly, purified articles are to be preferred to the crude minerals, in so far as this country is concerned, because of the cost of freight.

Stassfurt Salts seldom repay their Cost.

It is a curious fact, brought out by European experience, that, while phosphatic and nitrogenous fertilizers often repay their cost at once, and sometimes in a very striking way, dressings of plain Stassfurt salts have, as a general rule, given little or no money profit in fertile regions, excepting in the case of tobacco, and sometimes in the case of potatoes grown for table use. As regards pastures also, Voelcker has noticed that while potash salts, used either by themselves or admixed with superphosphate, sometimes considerably increase the herbage, the result is often disappointing in an economical point of view. When applied to clover, to beets, and even to grain, the potash salts improved the appearance of the crops and increased the burden of them, but in very many instances not to a profitable degree. Sulphate of potash has perhaps, on the whole, done rather better than the chloride; but, with the exception of tobacco, and perhaps potatoes, and sometimes on beet-farms and moor-lands, it has failed to yield the hoped-for profit.

The matter was summed up by Voelcker, in 1878, in the following words: "Potash salts are not much used in England for manuring purposes. Experience has shown that, on the great majority of soils, in a fairly good agricultural condition, the addition of potash salts to other artificial manures produces no decidedly beneficial effect upon the crops to which they are applied. On poor, sandy land, and on worn-out pastures and peaty soils, however, potash salts in conjunction with dissolved bones, or superphosphate, or a mixture of superphosphate and guano, have been used in England, as in other countries, with marked beneficial effects. In artificial manures for potatoes, the admixture of potash salts to phosphatic and nitrogenous fertilizing matters, has also been found useful."

It is remarkable withal that the Stassfurt salts have not in any large and general way endured the commercial test as to their fitness. There is neither doubt or uncertainty as to the manner in which phosphatic fertilizers have sustained that test, for the demand for phosphates has increased continually. But, after long-continued and persistent efforts, no market has yet been found for the Stassfurt fertilizers which can be compared with that for the phosphates. It is said, however, that the objection that potash salts, and other saline fertilizers, when applied to beets, are apt to diminish the yield of sugar, has been done away with by cultivating improved kinds of beets which are able to bear much larger dressings of saline fertilizers than could safely have been applied formerly. (Maercker.)

It is on poor land, and especially upon moor-land and upon light sandy soils that potash salts have done their best service. Very striking instances of their economic value are afforded by Schultz's experience with lupines, which continually gave good crops on poor land when dressed with kainit and with no other manure. So too in respect to peas and clover, which Schultz found to be somewhat grateful for phosphates on his cold, dry sandy soil, but which immediately developed great masses of stems and leaves — at the expense of flowers and seeds — when the land was heavily dressed with kainit.

Ashes better than Potash Salts.

In one word, experience has proved that the Stassfurt fertilizers, used as such, are decidedly inferior to wood-ashes. The explanation seems to be, that the sulphate and the chloride are devoid of the alkaline quality which is so marked a peculiarity of carbonate of potash, which, as is well known, is the effective agent in wood-ashes. And, in point of fact, European experience has shown that the Stassfurt salts commonly do their best work when they are applied to marled land, or when they are used in conjunction with lime, in which event a certain quantity of alkaline bicarbonate of potash would be formed by the reaction of bicarbonate of lime on the chloride or the sulphate, as has been explained under Composts.

Undoubtedly there is still much to be learned as to the best ways of using both sulphate and muriate of potash; but it will be well meanwhile to act upon this lime hint, and to study the plan of making composts with peat and a mixture of lime and muriate of potash, as has been suggested already. It may be true withal, that small additions of potash salts and other fertilizers to barnyard-manure, used in half its usual quantity, may be for certain crops an economical mode of application. The lack of profit above mentioned was in cases where potash salts were used, either by themselves, or in conjunction with other commercial fertilizers.

It needs to be said, however, that, when a mixture of lime and muriate of potash is used, there will naturally be produced more or less chloride of calcium, which is hurtful to some plants, and which, as Mayer has urged, may "bind" the land in some cases. It has not yet been determined whether this particular form of binding would always be hurtful for all kinds of soils. This is a point which might well have been talked about with those old farmers who formerly made and used composts with lime and salt. The binding could perhaps be avoided by applying the mixed fertilizers in autumn, for spring crops, and so giving time for the chloride of calcium to leach out of the land. It is not at all clear that this binding may not be due to bicarbonate of potash formed in the soil by the reaction of the potassium chloride with limestone and carbonic acid. Indeed, it is probable enough that the good effect of kainit on some sandy soils that have been marled — as proclaimed by Schultz at Lupitz, for example — may depend, in good part, on a mechanical improvement of the soil, by the action of potassium bicarbonate, whereby the power of the land to hold and to lift water has been increased. Compare the heading "Action of salt and lime in soils," in the Chapter on Sodium Compounds.

Sulphate of Potash may react well upon the Soil.

Heiden has argued in a somewhat similar way, that sulphate of potash may perhaps generally do better service than the chloride, because it produces a better class of compounds than the latter by reacting on the soil. Such useful compounds as gypsum and sulphate of magnesia may be produced when sulphate of potash acts upon loam, while from the action of chloride of potassium come the chlorides of calcium and of magnesium, which may readily do harm to plants. In this sense, it might be said therefore, even of the sulphates of low grades, that, in spite of their being contaminated with chlorides, they are comparatively speaking meritorious, and somewhat in proportion as the amount of sulphate of potash contained in them is larger. There is withal a good deal of field experience which goes to support the view that the low-grade sulphates are on the whole better than the mere chlorides. They lend themselves to a plan, commonly practised in Europe, of applying cheap, low-grade potash salts to such crops in a rotation as do not suffer from the presence of chlorides. Thus, when a generous dressing of kainit is applied to oats, this particular crop is helped, and the soil is at the same time charged with potash and left in fit condition for the subsequent growth of potatoes or sugar-beets. By the time when the potatoes, or beets, or what not, are to be planted, most of the chlorides of the fertilizer will have been washed out from the land, or, at the least, have been carried down into the subsoil; and it is to be noted that the maximum of time for the leaching process may be gained by applying the kainit the autumn before the oats are to be sown.

The fact that a comparatively pure juice may be obtained from sugar-beets fertilized with sulphate of potash, but not from those dressed with muriate of potash, is supported, curiously enough, by observations made by Hilgard in California, whence it appears that satisfactory yields of sugar may be obtained from beets grown in soils which contain appreciable quantities of sulphate of soda, while the beet-juice is practically worthless when taken from soils which are contaminated with common salt. Loew has suggested that the action of carbonate or bicarbonate of lime in the soil to change the magnesium chloride in the fertilizer to carbonate of magnesia will be another advantage gained by applying kainit in the autumn.

Muriate of Potash diffuses tolerably easily.

There is one advantage to be credited to the chloride, however, in that it diffuses in the soil rather better than the sulphate. Potash is so readily fixed by the double silicates and humates in loam, that it is not easy to secure a proper dissemination of the potassic fertilizers. No matter how deeply they may be ploughed under or harrowed in, the potash is apt to be absorbed and held at precisely those spots where the particles of the fertilizer first came in contact with the earth. But this is a great disadvantage in many cases, especially where it is desired to manure the subsoil evenly, in anticipation of growing deep-rooted crops like sugar-beets or clover.

Experiments have shown that the potash in the chloride is fixed decidedly less easily and less rapidly than that in the sulphate, so that a better diffusion may be had by means of it. Unfortunately, the chloride is not applicable for the growth of sugar-beets. But the crystalline double sulphate of potash and magnesia, already mentioned, appears to be able to diffuse potash in the soil even better than the chloride. It is, moreover, a pure substance, free from chlorides, and on this account specially worthy the attention of beet-root and tobacco-growers. In such cases as this, and when mixtures of Staśsfurt salts and lime are used, the fertilizer will naturally be applied in autumn, so that considerable time may elapse before any crop is to be sown or planted.

In order to aid the distribution of the potash, it is well to plough under the Stassfurt salts immediately after they have been strewn.

Experiments on the Diffusing of Potash.

Treutler has made an extended study of the question how best to hinder or counteract the fixation of potash by the soil, so that this fertilizer may be made to diffuse itself into the subsoil and through all parts of the standing-room of crops. He found that bone-meal exerted a decided influence to hinder the fixation by the soil of the potash in sulphate, carbonate, nitrate, or chloride of potassium; and that several other fertilizers had some power to hinder the fixation of potash. Several saline fertilizers decidedly hindered the fixation of potash from carbonate of potash in particular. Farmyard-manures of various kinds hindered the fixation of potash from the sulphate and the chloride, while they increased the fixation as regards carbonate and nitrate of potash.

Next to bone-meal, humus seemed to have the most marked solvent action when used with sulphate or with chloride of potassium, but it increased the fixation decidedly as regards carbonate of potash, and slightly as regards nitrate of potash. A mixture of humus and carbonate of ammonia had in general less solvent action than humus alone, or even than carbonate of ammonia by itself. Carbonic-acid water did not exhibit much solvent action, perhaps because the carbonic acid speedily escaped from it on coming into contact with the soil.

Nitrate of soda, used in conjunction with sulphate, carbonate, or nitrate of potash, increased the diffusion of the potash appreciably, but it did not do so when used with chloride of potassium. Gypsum, Epsom salt, and especially superphosphate of lime, had some solvent action, excepting when used with nitrate of potash. But chloride of sodium exhibited very little solvent action in any case.

The fixation of potash from chloride of potassium was hindered by bone-meal, humus, manures, dung-liquor, carbonate of ammonia, superphosphate, gypsum, Epsom salt, and carbonic-acid water. Indeed, with the exception of common salt and nitrate of soda, all the substances tried by Treutler promoted the diffusion in the soil of the potash in chloride of potassium. It was noticed, as had been done before by other observers, that in general the fixation of potash from a solution of the chloride is less complete than it is from the sulphate and carbonate, or even from the nitrate.

Practical Rules for applying Potash Salts.

In default of any extended practical experience with the Stassfurt fertilizers, and their known inability to repay an immediate money profit in most cases, it will probably be well not to apply large quantities of them at any one time. The amount that a careful laborer would naturally scatter from his hand when sowing one of these salts upon a field would probably be a useful application to that crop in a rotation which stands in special need of potash.

In general, it may be said that potassic fertilizers, used judiciously, have approved themselves on many poor sandy and peaty soils — though by no means on all sands — as appropriate dressings for clover, peas, lupines, beets and potatoes. For such lands, some 400 to 500 lb. of kainit to the acre have been recommended.

It appears that the muriate is often applied at the rate of 125 to 250 lb. to the acre, and kainit at the rate of 700 to 900 lb., usually in conjunction with other fertilizers. They should be ploughed under. German dealers in fertilizers recommend that muriate of potash should be applied to heavy soils in autumn, and to light or sandy soils in early spring.

Heiden has argued that for sugar-beets, from 350 to 550 lb. of the double sulphate of magnesia and potash, or from 175 to 250 lb. of true sulphate of potash, may be applied to the acre. For potatoes, he recommends from 250 to 550 lb. of the sulphate of magnesia and potash, or from 135 to 250 lb. of sulphate of potash; while for mangolds the cheaper muriate of potash may be used, at the rate of from 200 to 400 lb. to the acre. For lupines, clover and flax, he suggests from 350 to 550 lb. of the 80 % muriate to the acre.

As regards the profitable use of potash salts for fertilizing potatoes, Bretschneider has insisted that, although much depends upon the mode of their application, moderate dressings of the Stassfurt fertilizers are decidedly useful. In so far as mere increase of crop is concerned, he holds that it does not much matter whether the fertilizer is used in the form of a sulphate or of a chloride, provided as much potash is applied to the land in the one case as in the other. He urges that potash salts should be strewn broadcast after the land has been harrowed flat, and then be worked in slightly with a smoothing harrow before any furrows are drawn, or drills marked out for the reception of the seed. By proceeding in this way an increase of crop may confidently be looked for. Experiments upon potatoes by Magerstein also go to show that this plant needs potash in the earliest stages of growth. He urges that for potatoes, potassic fertilizers should be applied to the land some time before the sets are to be planted, and that the fertilizer should be strewn evenly and worked into the soil deeply and thoroughly.

Harm from Saline Manures.

On the other hand, potash salts should never be put into the hills where they might come in contact with the seed potatoes, nor be strewn in the furrows, since they are apt to hinder the sprouting of the seed and to destroy the young sprouts. Nor should the salt be strewn as a top-dressing, for in this case much of the fertilizer would be left where the rootlets can have no proper access to it. Both for potatoes and for beets, it is well to apply muriate of potash to the land during the autumn before planting, or to apply it for fertilizing the previous crop. Under the head of Soda, it will be seen that many plants can bear an application of common salt or of sea-water when mature which would kill them if they were young. The same remark is true of the Stassfurt salts, especially, it would appear, of the muriate; and it has sometimes been recommended that, in applying this compound to root-crops, it should be worked into the soil at the time of the first or second hoeing, in order to be sure that none of it can come into contact with the young plants. In any event, however, there is a certain amount of risk in applying saline manures to growing crops. Voelcker, in speaking of potatoes, has said, "I am more and more constrained to look upon all very soluble saline manures as rather dangerous agents, for I have noticed, over and over again, the injury which these kinds of fertilizers produce in dry seasons, especially if they are applied rather late in the spring. Unless common salt or potash salts can be applied to the land quite early, or, at all events, not later than the beginning of March, I believe it would be better, in 9 seasons out of 10, not to make any use of these very soluble matters, which require to be thoroughly washed into the soil if they are to benefit the crops for which they are used." As has been said already, this remark is particularly true of chlorides, which are much more apt to do harm than the sulphates are. (Schuebler.)

Mr. Gregory remarks that he has found it dangerous to apply kainit in the hill where small seeds, such as those of the cabbage, are to be planted. It is better, he says, to spread the fertilizer around the plants just before their second hoeing. This subject of the injury done to crops by saline fertilizers will be treated of more at length under Sodium Chloride.

According to Maercker, the results of German experience teach that there is no use in applying kainit as a top-dressing to old meadows situated on rich marsh-land, or to those the soil of which consists of loamy sand, poor in lime. But it is none the less true that in the great majority of instances, where kainit has been applied to old mowing-fields in that country, useful results have been obtained, provided of course the land was moist enough for the profitable production of grass. Particularly good results were obtained on meadows the soils of which were composed of sand, peat, or moor-earth, and of sandy loam. Usually, the yield of hay was increased by the kainit, and often to a notable extent, though sometimes only the aftermath was improved. The destruction of moss was a frequent gain, and occasionally it happened that better kinds of grasses, or clover, appeared upon the fields. Generally speaking, good results were obtained when the kainit was applied at rates ranging from 350 to 600 lb. to the acre, but it often failed to serve any useful purpose on mowing-fields when applied in quantities as small at 175 lb. to the acre or as large as 700 lb. For the region in question, it appeared to be best to apply kainit to mowing-fields either in November or February. Frequent failures attended the application of it in October, March, and April.

On some German moor-lands, continued applications of kainit have been found to be hurtful, apparently by hindering nitrification; perhaps also the presence of magnesium salts may have done harm to the crop itself.

Multitudes of field experiments with potash salts have been reported in the German journals, and the results of them vary not a little. The following table of results obtained by Stoeckhardt may serve in some sort as an epitome of the matter. The fertilizers were applied in this case to potatoes on worn-out land. It was a light, sandy soil charged with humus. Tubers were harvested from 1½ acres of land as follows, in German pounds: —

	Weight of Crop.	Per Cent of Starch.
600 lb. nitrate of potassium	12,340	23.0
" sulphate "	11,150	21.6
" carbonate "	10,720	24.2
" chloride "	8,850	20.6
" tartrate "	6,640	24.0
" phosphate "	5,950	24.0
No manure	4,840	23.2
600 lb. silicate of potassium	819[1]	.

Chlorides hinder Tobacco from Burning.

The objection to chloride of potassium as a manure for tobacco depends upon the fact that leaves of this plant which have been grown upon land rich in chlorides are apt not to burn readily when dry, apparently because the easily fusible chloride of calcium accumulates in the leaves and, by melting when the tobacco is burned, covers the carbon particles and shields them from the air. As A. Mayer has urged, phosphates (as well as borates) would interfere with the combustion of tobacco even more decidedly than chloride of calcium, because of their ready fusibility. Mayer found that chloride of potassium by itself does not hinder tobacco from burning, though chloride of sodium does somewhat. Indeed, tobacco-leaves soaked in a solution of chloride of potassium and then dried burned the better for the addition.

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[1] In this case the plants were distressed.

According to Mayer, the prejudice which has existed for some years against chlorides in tobacco manures needs to be modified somewhat. "We would come nearer the truth," he argues, "if we were to say, The more ashes there are in a tobacco and the more potash there is in these ashes, and the smaller the amount of non-volatile acids in combination with the potash, so much the better will the tobacco burn. The more phosphate and lime in a tobacco, so much the worse for its combustibility. The presence of much chloride of calcium or of sulphate of lime has an unfavorable influence also."

Nessler also admits that the ability of tobacco-leaves to hold fire is apt to be considerably influenced by other ash-ingredients beside chlorides as well as by certain organic matters, such for example as the difficultly combustible fats and albuminoids. Since some of these organic matters disappear during the fermentations which occur when tobacco is cured and stored, many kinds of tobacco are improved as to their combustibility by keeping, though there are other kinds which are not improved. It is to be presumed, however, that those tobaccos which are not susceptible of improvement must be rich in chlorine and poor in potash, while the samples which improve on keeping probably contain much potash in proportion to the amount of chlorine, and need only to be freed from the non-combustible organic matter in order that they may burn freely.

Nessler has concluded as a result of his examination of 46 samples of tobacco from different parts of Baden, which had been grown on soils of various characters, that the more potash and the less chlorine a leaf contains the longer will it continue to burn when lighted, and that the higher the proportion of the potash is so much the more chlorine may be present without seriously affecting the combustibility of the tobacco. So too, the less chlorine there is in a leaf the less potash is necessary to ensure ready combustibility. He concludes that tobacco which is to be used for cigars should contain at least 6 times as much potash as chlorine, and that no tobacco which contains less than 2.5 % of potash will burn well if there is present in it more than 0.4 % of chlorine. As an example, he cites the case of a Sumatra leaf containing 0.64–0.78 % of chlorine and 5 % of potash, which burned very well, while a tobacco with 0.4 % of chlorine and 3 % of potash burned badly.

Some of the older experiments which illustrate the bad effect of chlorides are given in the following tables. Nessler, for example, watered a number of individual tobacco-plants, at the end of July, with solutions containing each 15 grams of the salt to be examined. The plants were growing in fields in two different townships. After the harvest the leaves were analyzed, and tested as to their power of holding fire:—

EXPERIMENTS IN CARLSRUHE.

Kind of Tobacco.	Kind of Fertilizer used.	The Leaves glimmered Seconds.	Ashes.	100 Parts of the Leaves contained		
				Carbonate of Potash.	Chlorine.	Water.
Maryland.	No manure	36	....	....	....	..
"	Chloride of potassium . .	9	30.8	0.83	1.14	..
"	Sulphate " . . .	43	28.0	1.10	0.43	..
"	Nitrate " . . .	62	....	....	....	..
Java.	No manure	43	....	....	....	..
"	Chloride of potassium . .	20	32.6	0.83	1.42	..
"	Sulphate " . . .	67	30.4	0.37	0.71	..
"	Nitrate " . . .	31	28.2	0.64	0.71	..
Nuremberg.	No manure	9	....	....	....	..
"	Chloride of potassium . .	14	38.9	0.29	1.63	..
"	Sulphate " . . .	15	25.7	1.40	1.56	..
"	Nitrate " . . .	31	21.1	1.65	0.43	..
	EXPERIMENTS IN SECKENHEIM.					
Gundi.	No manure	8	....	....	....	..
"	Chloride of potassium . .	5	19.9	0.60	2.13	12
"	Sulphate " . . .	31	18 9	0.42	1.50	14
"	Nitrate " . . .	45	17.2	1.57	2.20	14
"	654 kilos. potash superphosphate and 2,180 kilos. wool-dust to the hectare . . .	19	16.0	1.33	1.24	13
"	33 wagons farm-manure and 300 kilos. potash superphosphate	22	18.7	2.30	1.49	14
"	32 wagons farm-manure and 30,400 litres dung-liquor .	17	18.8	3.80	1.85	15
"	25 wagons farm-manure and 19,300 litres dung-liquor .	7	18.0	2.90	1.49	12
"	15 wagons farm-manure and 15 wagons night-soil . .	173	19.9	3.22	0.71	13
"	40 wagons farm-manure to the hectare	8	23.1	1.84	2.00	15

It appears that, with one exception, the application of chloride of potassium diminished the combustibility of the tobacco. One of the most remarkable results is the last item but one in the table, for night-soil usually contains a considerable proportion of chlorides, and is thought to be apt to injure the combustibility of tobacco. It occurred to Nessler that, in this instance, the preceding crop (mangolds) might have taken up a great quantity of chlorides from the field, and that the land might thus have been freed from them; and, on subjecting this idea to the tests of experiment and observation, it was seen to be true.

Ways of Avoiding Chlorides.

In one instance it appeared that a crop of mangolds, grown on land charged with chlorides, took off in the roots 52 kilos. of chlorine from a hectare, and 176 kilos. of potash; and in the leaves, 13 kilos. of chlorine and 10 kilos. of potash. It appears, indeed, that several crops may be useful forerunners of tobacco on this account. Tobacco itself is perhaps the best of these cleansing crops, but stubble turnips are good, provided the leaves as well as the roots are carried off from the land. Oats and vetches also (sown as meslin) take up much chlorine, and a smaller proportion of potash than of chlorine. Either of these crops might serve to remove chlorides from soils which had become unduly charged therewith by improper methods of fertilization, and so might crimson (annual) clover, grain-crops, hemp and rape. In case the land were to be heavily dressed with potash salts free from chlorine, even fodder-corn (maize), sugar-beets, red clover or lucern might be grown before tobacco, though there is a certain objection to these crops, in that they take up very large quantities of potash in proportion to the amount of chlorine taken. In case potatoes, sugar-beets or chicory, which contain from 10 to 20 times as much potash as chlorine, were to be sold off a farm, much potash would be removed from the soil, while much chlorine might be retained in the leaves, which would naturally be used on the farm either as fodder or as manure. Hence neither of these crops is to be commended on a tobacco-farm, unless, indeed, they are fertilized with potassic manures of kinds that are free from chlorine.

Among the earliest systematic experiments relating to the influence of chlorides and of potash on the combustibility of tobacco, were those of Schloesing, which are given in the following table. They were made on poor sandy soil that was somewhat calcareous, and clayey enough also to be somewhat tenacious. The soil contained very little chlorine, sulphuric acid, or potash. One interesting point which these experiments illustrate is, that while sulphate of potash gives much potash to the plants, very little sulphuric acid is taken up by them. The result is similar to that obtained by Boussingault in his experiments with gypsum.

No. Plot.	Kilos. of Fertilizer to the Hectare.	100 Parts of the Leaves, containing 10% of Moisture, contained Parts of					Combustibility of Cigars made from the Leaves.
		Potash.	Lime.	Magnesia.	Sulph. Acid.	Chlorine.	
1	No manure	1.04	7.73	0.99	0.99	0.70	Almost incombustible, did not hold fire.
2	3,300 flesh and 11,500 washed peat	0.98	7.48	0.81	0.93	0.55	" "
3	666 sulphate of potash	2.66	6.58	0.78	0.97	0.43	Readily combustible, held fire 3 minutes.
4	570 chloride of potassium	1.74	7.17	0.73	0.87	1.64	Slightly combustible, held fire 1 minute.
5	773 nitrate of potash	2.13	6.26	0.64	0.79	0.38	Readily combustible.
6	265 carbonate of potash	1.65	7.34	....	0.96	0.44	Combustible, held fire 3 minutes.
7	530 " "	2.24	6.24	0.65	0.84	0.42	" "
8	1,060 " "	2.50	6.61	....	1.05	0.54	Readily combustible.
9	432 chloride of calcium	1.16	8.47	0.97	0.85	1.77	Absolutely incombustible.
10	213 chloride magnesium	0.82	8.29	1.09	0.77	1.69	" "
11	500 silicate of potash	1.39	7.74	0.92	0.98	....	Moderately combustible, held fire 1 minute.
12	1,000 " "	1.99	7.44	0.78	1.04	0.50	Passably combustible.

It will be noticed that the plots 1, 2, 9 and 10, to which no potash was applied, all gave bad burning tobacco; that those treated with chlorides, 4, 9 and 10, gave tobacco that contained three times as much chlorine as the others, showing that this element is easily assimilated; and that the tobacco which contained this large proportion of chlorine burned badly.

Best Manure for Tobacco.

For the reasons above stated, and from the results of practical experience, Nessler argues that, for growing tobacco, farmyard-manure cannot well be replaced by artificial fertilizers, although the action of the manure may be improved by the addition of the artificials. In order to be fit for use on tobacco, a manure should contain at least 600 lb. of potash for every 100 lb. of chlorine. It will be less and less suitable according as the proportion of chlorine is larger. Night-soil is by far the worst of the so-called natural manures, since it contains no more than 40 lb. of potash for each 100 lb. of chlorine. Even kainit contains 50 lb. of potash for 100 lb. of chlorine.

Good cow-manure, from farms not manured with fertilizers that contain chlorine, is excellent for tobacco, but horse-manure is not so good as cow-manure. Neither the dung of sheep nor of swine is to be commended. Liquid manure, i. e. the drainings of dung-heaps, which in some parts of Europe is largely used upon tobacco, may vary widely as to the amounts of chlorine and potash which are contained in it, according to the character of the fodder eaten by the animals, and as to whether or not they are given salt to eat.

Nessler noticed that for each 100 lb. of chlorine the quantity of potash in liquid manure varied from 182 lb. to 917 lb. He commends it as a good manure for tobacco, in case it is not surcharged with chlorine and is ploughed under before the crop is planted; but if it were to be applied to growing plants of some size, it would be apt to retard the ripening of the crop and to make the leaves "spongy."

Ordinarily, neither kainit, carnallite, nor any other of the Stassfurt compounds which contains much common salt, should be used upon a tobacco-farm, since they would tend to charge the forage with chlorides, and consequently the manure produced upon the farm. Nessler recommends applications of 1,000 to 1,400 kilos. of wood-ashes to the hectare, or 200 to 400 kilos. of sulphate of potash, to be applied in the spring to medium soils, but to be ploughed under in the autumn if the soil is deep. In the spring there may be applied also, before planting, if the land has not already been too heavily dunged, from 150 to 200 kilos. of nitrate of soda to the hectare.

As a rule, nitrate of soda should not be applied to tobacco while the plants are growing, lest it hinder the ripening, though in case it should happen that all nitrates are washed out from the land by persistent rains in early summer — as is shown by the plants ceasing to grow, and losing their dark green color — it may be well to strew upon the land 100 to 150 kilos. of nitrate of soda to the hectare, provided, however, that the plants have not yet got to be large.

The double sulphate of magnesia and potash may be used instead of the simple sulphate, and it is to be noted that on light sandy soils it might sometimes be practicable to use even muriate of potash, if it were applied not directly to the tobacco but to a preliminary forage crop, for from such soils chlorine is washed out by rain-water so much more rapidly than potash is, that not enough chlorine to do much harm is left in the soil.

Nessler found as a rule that while tobacco grown on sandy land contains as much potash as that grown on heavy land, it contains much less chlorine. On the average of his experiments, tobacco from sandy land contained 0.29 % of chlorine, while that from heavy land contained 0.92 %. He could not detect any noteworthy quantities of chlorine in tobacco grown on such land after preliminary crops which had been manured in various ways. Herein is found one reason for the practical rule that, for producing good smoking tobacco, light sandy or medium soils are better than heavy, clayey land.

It is even possible to grow fairly good tobacco on farms manured with night-soil, provided the soil is sandy; and it has been noticed in Europe that tobacco-land which has long been manured with night-soil (rich in chlorides), or other unfit manure, yields freer burning tobacco in rainy seasons than that obtained in dry years, when as much as 2 % of chlorine has sometimes been detected in the leaves. The presumption is that the chlorides have been washed down into the subsoil in the one case, and brought up towards the surface of the soil in the other.

Stassfurt Salts may preserve Manure.

Several of the low-grade minerals and products from Stassfurt are well suited to be used instead of gypsum in horse- and cow-stables, and in sheep-stalls, to keep them sweet; and even on dung-heaps, to hinder that form of putrefaction which occasions loss of ammonia. They may be used, perhaps even more economically than gypsum, to "hold" ammonia, as the common saying is; for, as is well known, chloride of magnesium (and chloride of calcium also) has the power to absorb and fix very considerable quantities of ammonia. Eichhorn found, for example, that one grm. of anhydrous chloride of magnesium could absorb 1,187 c. c. of ammonia gas (and one grm. of chloride of calcium 1,437 grms.), while a grm. of spruce charcoal absorbed no more than 105 c. c. of ammonia. It may be said, also, of these saline preservatives that they act as germicides to hinder decay and putrefaction much in the same way that common salt acts when applied for the preservation of flesh, fish, hides, etc.

Fittbogen has made numerous trials with stall-fed sheep, at temperatures ranging from 54 to 69° F., to determine how much of the nitrogen in the fodder was retained in the manure according as one or another of the preservatives was scattered upon it. He was well satisfied with their action, having obtained results which are given, very much condensed, in the following table. The following amounts of the fodder nitrogen were found in the manure, when there was used, —

	Per Cent.
No preservative, from	71 to 82
0.10 kilos. gypsum to each sheep, per day, from . .	88 to 90
0.08 " kainit " " " . . .	84 to 94
0.12 " carnallite " " " . . .	87 to 97
0.06 " refuse salts from the Stassfurt factories . .	90

In practice, it would probably be sufficient to use half a pound per diem either of kainit, or carnallite, or gypsum, for each horse or cow, or for every 10 sheep. The potash compounds would be just as valuable, when used as fertilizers indirectly in this way, as if they were put upon the land as such.

Troschke found that while carnallite strewn in stables absorbed 9 % of ammonia, kainit absorbed only 4½ %; though, as he remarks, the large proportion of chlorides in carnallite might sometimes be objectionable. Maercker also has suggested that it will be well to avoid those salts which are rich in chlorides in cases where the manure is to be used for tobacco or sugar-beets. He urges, furthermore, that the tendency to absorb moisture from the air, exhibited by salts which contain much magnesium chloride, may make them inconvenient of application in some cases.

Morren found that the loss of nitrogen from decaying horn-meal was almost wholly prevented when 10 % of kainit was mixed with the horn. The mixture remained neutral instead of becoming alkaline, as happened when the moistened meal was allowed to ferment without the kainit.

The results given in Fittbogen's table manifestly refer to tolerably fresh manure. Other experiments have shown that the preservative influence of kainit and gypsum is not necessarily permanent, since considerable losses both of the dry matter and the nitrogen in the manure thus treated have been noticed after a few months' time. Troschke found at the end of 3 months that a loss of 20 % of the dry substance and 10 % of the nitrogen had occurred in manure which had been mixed with kainit, and that 19 % of the dry substance and 32 % of the nitrogen had disappeared from manure which had been mixed with gypsum. He found that gypsum fixed ammonium carbonate more freely than either of the Stassfurt salts, and that among the latter kieserit was the most effective. Heiden also found that kainit was less effective than gypsum for fixing ammonium carbonate.

In more recent experiments by Holdefleiss, heaps of fresh cow-dung were mixed with kainit, etc., and then left exposed to the weather during 7 months. At the end of this time, the heap to which kainit had been added still retained its original texture, and it was manifest that the dung had undergone no great amount of decomposition, while a similar heap of plain cow-dung was very much decayed, and so was a heap that had been mixed with phosphatic gypsum, as well as another that had been covered with earth. Some of the results of these trials are set forth in the following table:—

From 6-ton heaps of	Plain Cow-Manure.	Dung and Kainit.	Dung and Phosphatic Gypsum.	Dung covered with earth.
Loss of dry matter in 7 months, per cent	31.2	11.9	22.5	....
Loss or gain of nitrogen, per cent	23.3 (loss)	0.15 (gain)	4.6 (gain)	2.2 (loss)

The large loss of nitrogen from the heap of plain manure is noteworthy, and so are the gains of nitrogen in the heaps charged with gypsum and kainit. As regards the preservation of nitrogen the covering of earth did good.

At the close of these trials, the several heaps of manure were used for field experiments on potatoes, and it appeared that, as compared with unmanured plots, the dung which had been preserved with kainit gave a smaller yield of tubers than were got from the heaps of dung that had been treated with gypsum or covered with earth. The yield from the heap of plain dung, however, was smaller than that from any other heap. The quality of the kainit potatoes was low, since they contained a comparatively small percentage of starch. The gypsum heap gave a larger yield of potatoes than either of the others.

Value of Potashes.

American potashes, which consist essentially of a mixture of hydrate and carbonate of potash, and usually contain some 60 % of real potash, may be had nowadays at about 5 cents the pound at wholesale. Hence the pound of real potash in them would cost about 8 cents, while it can be obtained for 4.5 and 5.5 cents in the form of muriate and sulphate of potash. In view of the ability of the caustic alkali to decompose and dissolve bones, and to excite fermentation in heaps of peat, weeds, and other vegetable matters, as has been explained under the head of Composts, it may perhaps sometimes be good policy for the farmer to buy what potash may be needed for his land in the shape of "potashes," rather than in that of sulphate or of chloride of potassium. Although the real potash (K_2O) in the "potashes" may cost much more money than it would if bought in the form of a neutral salt, it might occasionally be true that the caustic alkali would be the cheaper substance for the farmer to buy, because it is really a source of two kinds of power. After it has made the peat, or bone-meal, or weeds, or what not, ferment, it is still as useful as ever as a source of potash for the crops. "Potashes" are here specially insisted upon, because they are a compact, concentrated, merchantable article, readily obtainable; though of course, if wood-ashes can be got, the alkali in them could be bought for less money, because ashes are a crude unmanufactured material, upon which no labor has been expended except the cost of collecting and transporting them.

It is worthy of remark that much caustic soda is sold nowadays by retailers under the misleading name "potash," and that there are many localities in this country where real potash is no longer kept in store by country shopkeepers. The genuine article can still be obtained, however, without any difficulty, either directly or indirectly, from the city merchants who deal in potashes.

Nitrate of Potash.

Nitrate of potash is a powerful manure, as has been said under the head of Nitrogen Compounds. It is often formed in the soil, no doubt, and does good service there in feeding crops, but it has hitherto rarely been employed as a commercial manure because of its high price; i. e. it has been worth too much for other purposes, such as the manufacture of gunpowder, to be available for agriculture. Owing, however, to the great reduction in price which has resulted from the working of the Stassfurt mine, nitrate of potash is nowadays used with advantage in cultivating tobacco. Here the quality of the crop is of paramount importance, and it "pays" to feed it with the best. So, too, excellent potatoes may be grown by manuring with nitrate of potash.

The old plan was, instead of using nitrate of potash directly, to apply a mixture of nitrate of soda and muriate of potash; and for grass and grain this mixture is well enough, but the chloride of potassium is objectionable both for potatoes and tobacco, as well as for sugar-beets, in that it is apt to hurt their quality. Hence the modern use of nitrate of potash in these special cases. It may be asked, however, whether a mixture of nitrate of soda and sulphate of potash of the highest grade might not be used with advantage instead of pure saltpetre. In Dreschler's field experiments on potatoes, it appeared that, while potash in the form of nitrate of potash did much better service than when in the form of kainit, the chief gain depended on the fact that the tubers were of larger size in those instances where nitrate of potash had been used.

Saltpetre Waste.

At gunpowder works, and other places where crude saltpetre is refined, a waste product containing some sulphate of potash and a little nitrate of potash, together with a good deal of common salt and sulphate of soda, may be procured. As has been explained under the head of Nitrates, this waste product often has considerable value as a fertilizer, though it needs to be analyzed because different samples of it vary widely as to their composition. So also where saltpetre is manufactured from nitrate of soda and muriate of potash, the common salt which forms as an incidental product is sometimes contaminated with noticeable quantities of potash and of nitrates. In 12 samples of such refuse salt examined by Swindells, there was found 5.6 % of potash on the average. In one sample he found 9 % of chloride of potassium, and 6 % of nitrate of potash.

Prussiate and Cyanide Residues.

In the manufacture of potassium cyanides, several by-products are obtained which must possess considerable agricultural value. For example, a sample of dark-gray "prussiate residue," that was readily soluble in water and highly alkaline, which I examined some years since, contained 43 % of potash (K_2O) and half of one per cent of phosphoric acid; and other American samples are reported to have contained as much as 54 % of potash. Another residual black product from prussiate works contains a large proportion of matters insoluble even in acids, and is, when freshly prepared, heavily contaminated with ferrous oxide and ferrous sulphide. According to Karmrodt, it may contain some 10 or 12 % of potash and 5 or 6 % of phosphoric acid as well as much lime. When weathered, to oxidize the iron compounds, this material would be a useful fertilizer.

Another residual product (cyanide residue), which may contain 50 % or more of potash, is obtained by evaporating the mother liquor from which pure cyanide of potassium has been separated, by way of crystallization, to be used for electroplating.

Potash aids in translocating Starch.

As will be seen in another chapter, compounds of potassium are of the utmost importance in vegetable physiology, since they play an essential part in the process of assimilation by which the carbon obtained from the air is converted into organic matter. It has been established with tolerable certainty that a considerable amount of potash must be present in the leaves of plants in order that sugar and starch may be formed there. Thus Nobbe and several other observers have found that no starch is formed in the chlorophyl grains when potash is absent, and that without potash plants will not grow. On one occasion, Nobbe kept some buckwheat-plants alive during three months, without any gain of weight or any production of vegetable matter, by maintaining them in solutions which contained all other kinds of plant-food excepting potassium. But on adding to these solutions a small quantity of one or another potash salt, carbon was assimilated, and it could be seen with the microscope that starch was formed in the leaves.

As bearing upon this matter, it is noticeable that plants which are specially rich in carbohydrates contain much potash. Even if there were no experimental proof that the presence of potassium is necessary for assimilation, there would still be a strong presumption that there is an intimate connection between potash and starch (or other carbohydrate) analogous to that which has long been noticed to subsist between phosphates and albuminoids.

According to A. Mayer, this supposition would have applied to cellulose as well as to starch, for, as De Saussure remarked long ago, potash is most abundant in those parts of plants where growth is most active, notably in twigs and leaves, i. e. in places where cellulose is in process of deposition. Lawes and Gilbert have noticed that the proportion of potash in the ash of wheat-grain is larger in proportion as the grain is better matured, and contains a larger proportion of starch. In the potato, also, they found a greatly increased amount of potash in the heaviest crops, i. e. in those in which the largest amounts of starch had been formed.

Acid Potash-salts in Plants.

It is to be noted, furthermore, as a fact of observation, that those juices of plants which are noticeably sour, such as lemon juice, the sap of rhubarb stalks and sorrel leaves, the juice of sour apples, gooseberries, grapes, and the like, commonly contain an acid salt of potash. In such cases the acid combined with the potash is usually either citric, malic, tartaric or oxalic.

It has been noticed withal, that tobacco leaves well charged with the potash salts of the vegetable acids now in question burn readily, in a manner very unlike leaves that contain chloride of calcium. Hence one advantage in feeding tobacco-plants with appropriate potassic fertilizers, over and above the benefits due to any increase of the amount of crop. The presence of much carbonate of potash in tobacco-ash, as set forth in the table on page 504, is an indication that considerable quantities of the organic compounds above mentioned (or of nitrates) were contained in the leaves. When subjected to heat, these organic potash salts swell up during the process of decomposition so that the charcoal is left in a spongy, easily combustible condition, the final product of their decomposition being carbonate of potash.

This question of combustibility has been studied in detail by A. Mayer who impregnated filter-paper with various saline solutions and noted how the different specimens behaved when burnt. He found in general that the more readily a paper burns with flame, and the more difficult it is to extinguish the flame, so much the smaller is the capacity of the paper to glimmer and to "hold fire." Many organic substances promote flaming and hinder glimmering, but inorganic matters — excepting phosphates (especially acid phosphates) and some salts of lime — are generally helpful for glimmering and prejudicial to flaming. The improvement in combustibility of many samples of tobacco by fermentation (and in some cases by leaching) is due to the alteration, destruction, or removal of organic matters while most of the mineral matters remain behind.

Beside compounds of organic acids and alkalies, the nitrates, sulphates and carbonates of the alkalies, and even chloride of potassium. were found to promote glimmering.

Soda salts were less helpful than those of potash, and salts of lime and magnesia were not so good as those of soda. Contrary to anticipation, the glimmering of paper was increased rather than diminished by impregnating it with chloride of potassium or even with chloride of sodium.

Mayer found it comparatively easy to change difficultly combustible tobacco to easily combustible by hanging the leaves in a half per cent solution of acetate or nitrate of potash, during 24 hours, and then drying them. Mere sprinkling of the leaves with the saline solution will not answer. Soaking is essential to success, for not only is the tobacco impregnated with the salt which promotes glimmering, but much organic matter is leached out from the leaves, as well as some chlorides. Meanwhile the tobacco loses both weight and strength. White ashes may be obtained by soaking the leaves, as above, in a half per cent solution of acetate of lime.

The leaves of tobacco grown in fertile soils often contain such considerable quantities of nitrate of potash that they burn more freely than they would otherwise, and it is sometimes well to manure tobacco with saltpetre on this account as well as because of the fact that the nitrate manuring increases the crop. Dressings of carbonate of potash also, and of wood-ashes, have often been found to improve the combustibility of tobacco, and Mayer has urged that the nitrate and the carbonate should consequently be preferred for tobacco even to the pure sulphates. He has suggested that precipitated phosphate of lime, or double superphosphate, or even phosphatic slag may be better for tobacco than ordinary superphosphate, because the last named contains a larger proportion of sulphate (gypsum) than the others.

CHAPTER XXV.

MAGNESIUM COMPOUNDS.

MAGNESIUM is one of the elements absolutely necessary for the growth of plants. In the absence of it crops cannot prosper. But since magnesium compounds are found in tolerable abundance in most soils of fair quality, and in all soils that are dressed with stable-manure, comparatively little attention has been given to their employment as fertilizers.

It is true, indeed, that the amount of magnesium taken up by plants is rather large. Thus, the ashes of wheat-grain contain about 12 % of magnesia against 3 % of lime, and the ashes of peas 8 % of magnesia to about 4 % of lime, and so with various other seeds and grains. It is noteworthy, moreover, that a comparatively large proportion of magnesia accumulates in the grain or seeds of the plant, and is in that way liable to be sold in the crop and carried away from the land. But it is also true that magnesia compounds are widely diffused in nature.

Small quantities of silicate of magnesia occur in many rocks, such as granites, syenites, dolerites, and the like. All limestones contain more or less magnesia, and the so-called "dolomites," or magnesian limestones, contain a great deal of it. Soapstone, serpentine, and the talcose slates are magnesian rocks. There is magnesia in ashes also, in bones and in sea-water. It is consequently an exception to the general rule when a soil is sterile through absence of magnesia. On comparing many analyses of American soils, Hilgard has found that those of rainy regions contain on the average about 0.225 % of magnesia, and those of the arid Western States — where the leaching action of rains is practically absent — about 1.411 %.

Modes of Action of Magnesia.

It may sometimes be true that the application of a small quantity of a magnesium compound to land will improve it. This fact has been observed occasionally in Germany, as a result of the application of the potash-magnesia minerals from Stassfurt.

It was shown long ago by Stoeckhardt, as the result of very extended experiments with magnesian limestone from the low lands of Saxony.

It is possible that magnesia, when applied as a manure, may act directly by serving as food for the plant, or it may be that it will act indirectly by expelling potash, or ammonia, or lime from the aluminous double silicates of these substances which exist in the soil. When applied in the form of a magnesian limestone, for example, the magnesia may perhaps help the lime to effect the expulsion of the foregoing ingredients of plant-food from the hydrous silicates that hold them. In other words, it may happen that the decomposition of the silicates is brought about more readily by a mixture of lime and magnesia than by lime alone.

The magnesian limestone, just now mentioned as having been examined by Stoeckhardt, gave a quicklime containing about 60 % of lime and nearly 40 % of magnesia; and it was found, as the result of wide and long-continued experience in Saxony, that this lime is a stronger and a more enduring fertilizer than that obtained from purer limestones. It may well be true, however, that the final effect of such lime may be mechanical rather than chemical. It may work to alter the texture and capillary condition of the soil, as will be seen under the head of Lime. It is easy to believe, at all events, that the more ready solubility of carbonate of magnesia in carbonic-acid water, as compared with that of carbonate of lime, may in some instances give to magnesian limes a real superiority over pure limes, as ameliorants of heavy land.

The argument is not infrequently urged that phosphoric acid is specially needed by plants, since it accumulates in their seeds. But manifestly the same reasoning would apply to magnesia also, which, as has just been stated, is found in seeds in larger quantity than occurs in the other parts of plants. The only difference between the two cases is, that phosphoric acid is rare, in the sense that it is sparsely distributed, while magnesia is abundant in most rocks and soils.

Magnesia sometimes Hurtful.

Doubtless one reason why so little has been said or done in favor of classing magnesia among fertilizing substances, is due to an old belief that it is liable to kill plants. This idea seems to have been suggested by the analyses of English chemists made at the beginning of this century. It appeared from the analyses in question, that certain limestones, which had sometimes been found in practice to injure crops, contained magnesia. Tennant moreover found, on mixing calcined magnesia with soils in which he sowed different kinds of seeds, that the plants either died, or were unhealthy, or vegetated in a very imperfect manner.

Hence magnesia immediately fell into bad repute, in spite of the fact that Sir Humphry Davy, on inquiring into the matter, found that there were cases in which these very magnesian limestones were used with good effect in field-culture; and that a number of specimens of limestone, which had been sent to him by farmers as peculiarly good, were found to contain magnesia. Furthermore, Davy called attention to the fact that, in one of the most fertile tracts in Cornwall, the Lizard, the soil contains much magnesia. "The Lizard Downs bear a short and green grass," he says, "which feeds sheep producing excellent mutton; and the cultivated parts are among the best grain lands in the county." So too, a narrow band of magnesian limestone which crosses the county of Yorkshire is neither sterile nor barren. "Although the soil is in general thin on the magnesian lime, yet it is a good light soil for arable culture, and with manure produces good crops. It produces good turnips, potatoes, barley and wheat." (Morton.) Davy made experiments by growing plants in soils mixed with magnesia compounds, whence it appeared that, although caustic magnesia is injurious when present in considerable quantity in the soil, it may be beneficial when mixed with peat, or when it exists in the form of a carbonate. Schuebler, in 1830, satisfied himself that carbonate of magnesia is wholly harmless, even when many per cent of it have been mixed with ordinary loam, and he called attention to the fact that the soils of several of the most fertile districts in Wurtemberg are derived from magnesian limestones, and contain more or less carbonate of magnesia.

Schuebler found, however, as Tennant had done, that calcined magnesia was very hurtful to plants when mixed with the loam in which they were growing, and he urged that the caustic magnesia hardens in the soil, like a hydraulic mortar, and forms crusts and clods which are decidedly inimical to vegetation. The fact, too, that, as ordinarily prepared, the magnesia is somewhat alkaline, may have a deleterious influence. Knop, in his turn, found that the presence of any salt of magnesia in the solutions employed for experiments in water-culture did manifest harm unless there was also present an abundance of lime, potash, or ammonia salts. By themselves, the magnesia salts bring about a peculiar alteration in the roots of the plants, and in that way soon cause the death of the plants.

Knop suggests that the bad effects sometimes produced by magnesia in field-culture can probably be prevented by using in conjunction with it a sufficient quantity of lime. He makes the further suggestion that, in view of the extremely easy solubility of chloride of magnesium, and the possibility of this salt's forming in some soils when they are dressed with chloride of potassium, that the last-named salt may be inferior as a fertilizer to sulphate of potash, which would never produce any such hurtful salt. But, as has been suggested already, this very formation of magnesium chloride in the upper layers of the soil might sometimes be advantageous, since it would be likely to react upon the potash silicate below and to set free potash from it.

Disorganization of Cells.

Knop's observation that lime is an antidote to magnesia has been corroborated by Loew, who maintains that the nuclei of cells contain a compound of lime and organic matter from which the lime may be removed by the action of certain magnesium salts, with destruction of the cell. He finds that sulphate, nitrate and chloride of magnesium may exert a poisonous action in this way which is comparable to that of oxalic acid and the oxalates. According to Loew, magnesia is so weak a base that whenever its compounds with the strong acids above mentioned come in contact with the lime compounds proper to the cells of plants, a reaction of the nature of a double decomposition occurs, which breaks up the lime compounds, and the cells also of which these compounds form a constituent part. But in case a sufficient quantity of lime or of a salt of lime are at hand, the magnesium salt will react therewith, and will have no opportunity to injure the nuclei of the plant-cells.

In consonance with these scientific observations, it has been observed by practical men that kainit may do harm when used upon poor sandy soils unless an abundance of lime is applied with it; and since kainit may contain some 15 % of magnesia, or say 12 % of magnesium chloride, it seems evident that the lime may do good by preventing the injurious action of the magnesia. Moreover, the fact that kainit often does better service on good land when applied in the autumn rather than in the spring, may be explained by referring to the slow decomposition of the magnesium salt by lime compounds in the soil, and by some of it being converted to the condition of a double humate, as well as to the leaching action of rain, which may remove some of the magnesium chloride from the soil.

It should be borne in mind that there are several localities on the Continent of Europe where soils resulting from the decomposition of dolomite are notoriously sterile and unfit for cultivation, and that the old prejudice against magnesia was greatly strengthened by the experience of German farmers with Abraum salt, and, indeed, with several other of the Stassfurt salts which contain magnesia. Soon after the opening of the potash-mine at Stassfurt, large quantities of the impure mineral, as dug from the earth, were applied for fertilizing purposes; but the results obtained were so varied, and the action of the substance was so uncertain, that it speedily fell into disrepute. The trouble was due, no doubt, to the large amounts of magnesium chloride (20 or 30 %) which the mineral contained. Compounds less highly charged with this impurity were soon substituted for the crude Abraum salt, and they have continued to be used in enormous quantities.

Kinds of Magnesian Fertilizers.

Little needs to be said with regard to the different forms in which magnesia might be applied to the land. The Stassfurt minerals, as well as products obtained from them, are always to be had; and were it not for the probability that lime made from dolomite has peculiar merit for improving the texture of certain soils, it might be said at once, and without reservation, that in some one of the potash-magnesia products from Stassfurt may be found the cheapest and the best source of magnesia. Lime rich in magnesia can usually be obtained readily. It would not be difficult to reduce dolomite to powder. If the use of it were found to be advantageous, this powder could be supplied in abundance at a very cheap rate. In case of need, it would be easy to treat soapstone or serpentine with oil of vitriol, and so get an impure sulphate of lime and magnesia. Epsom salt also is obtainable at cheap rates from sea-water, and as a residuary product in the manufacture of carbonic-acid gas from magnesite by means of sulphuric acid; and of late years chloride of magnesium is said to be procurable almost as a gift at Stassfurt.

The double phosphate of magnesia and ammonia, which is obtainable by adding a magnesium salt and some alkali to putrid urine, should likewise be borne in mind. The preparation of this compound has often been proposed as a device for saving some part of the phosphoric acid and ammonia now lost from cities, although, owing to the bulky character of the liquid to be operated upon and to sanitary considerations, the process cannot be regarded as one of general applicability. There can be little doubt, however, that sulphate of magnesia (common Epsom salt), or chloride of magnesium, or Abraum salt, may be added with advantage to the pit into which the drainings of the dung-heap flow, in cases where such pits are maintained.

It is plain that the farmer may free his mind from all care as regards magnesia considered as plant-food, by dressing his fields lightly, once in a while, with one of the low-grade Stassfurt fertilizers. With the exception perhaps of the very highest grades, all the Stassfurt products are highly charged with magnesium salts.

In speculating as to the condition in which magnesia may exist in the soil, the compounds specially to be considered are the carbonate, which is, comparatively speaking, readily soluble in carbonic-acid water, the double (and simple) silicate, humate, and phosphate, and possibly even the double phosphate of magnesia and ammonia.

CHAPTER XXVI.

LIME AND LIME COMPOUNDS.

The theory of the use of lime as a manure is a subject full of interest and importance, as well as of doubt and apparent contradiction. In some regions, the farmers are seen to apply lime to the land wellnigh universally, and in such quantities, indeed, that at certain seasons of the year the whole surface of the country is made white with it; while in other places, as in the vicinity of Boston, for example, it is easy to perceive that lime is held in small esteem by practical men.

It is hard to say positively why opinions should differ so widely, or to discover all the reasons which have determined the observed variations of practice. In one word, the subject of liming land is not yet thoroughly understood in all its bearings. It is not unlikely, however, that the mystery might even now be explained in good part, if not wholly, if some competent person would take the time and trouble to observe the facts in several localities, and to study the history of this particular branch of agriculture in the light of modern science. At all events, the problem could doubtless be solved if the results of the old experience were once thoroughly sifted, and properly set forth and formulated so that experiments could be devised understandingly, by which to settle the obscure points.

As matters actually stand, the student is met at the threshold of the inquiry by so many different statements, so many possibilities and probabilities, that the subject is made to seem less clear than it really is. As has been said, the contrasts between the current methods and practices of farmers in respect to the use of lime are very remarkable. Why is it, for example, that so little lime is used in Eastern Massachusetts? and why is it that such enormous quantities of it are used in other districts, such, for example, as some parts of Pennsylvania, of France, and of Germany, which have fallen under my own observation? At New York, Brooklyn, and New Haven the gas companies are said to sell their spent lime for almost as much as the fresh lime cost them, but in Boston no one will take the spent gas-lime as a gift.

Indifference towards lime, or objection to it, is by no means peculiar to this particular locality. It is notorious that in some parts of the world landlords have often absolutely forbidden their tenants by contract from using lime, and the employment of it in agriculture at the present day cannot in any sense be regarded as a general practice.

Another striking diversity is seen in the fact that most German writers claim that lime gives its best results on heavy land, while the earlier French writers often urged that the proper place to apply lime is upon light, open soils. According to Mr. Pusey, lime is considered indispensable, as an ordinary manure, on the west side of England, and is generally found utterly useless elsewhere in that country. He confesses his ignorance as to whether this difference may arise from soil or climate, but he believed that lime answers best in rainy climates on wet soils of primitive strata. At the West of England, he says, when land is first brought into use from waste, a heavy dressing of lime is a *sine qua non*. The impartial reader is in either case naturally inclined to believe positive affirmative statements such as these; and it is not easy to escape the conviction, that in both countries the customs have resulted from practical experience, and that in general the farmers are justified in their practices. In England it has been remarked by several observers that the introduction of artificial fertilizers has greatly lessened the importance of lime.

Manner of applying Lime.

The favorite way of applying quicklime is to bury it in little holes in the moist earth of the field, in the spring or the autumn, or to make little heaps of lime upon the surface of the land and cover them with earth. In either event the lime soon slakes and falls to a fine dry powder which is then spread upon the surface of the land. In a dry time the heaps of lime would need to be moistened with water, but usually the dampness of the soil is all-sufficient. On stiff land from 4 to 6 tons of quicklime are applied to the acre, sometimes even 12 tons. In spreading lime it is important that the day should be dry and the material powdery, lest a sticky paste be formed.

A Scotch writer has recently described his practice as follows. Plough oat-stubble as soon as convenient after removal of the crop. Next spring harrow across the furrows, as soon as may be practicable, to smooth the land; lay out the quicklime in heaps six yards apart, and cover the heaps immediately with the very damp soil. In 24 hours' time the lime will have fallen to fine powder, which must be spread speedily to avoid the risk of rain. Finally, harrow in the lime with a heavy harrow. Turnips are found to succeed well after this treatment, and to be comparatively free from the finger-and-toe disease.

According to H. Stewart, writing in New Jersey, a very convenient way of proceeding is to drop the lime in heaps of one bushel each at distances of 2 rods (33 feet) apart, which will give 40 bushels to the acre. These heaps are left exposed to air and rain until moisture enough has been absorbed by the lime to convert it to a fine, dry powder, which is then spread evenly with a long-handled shovel. The lime, being thrown 16.5 feet each way from the heap, will be evenly distributed over the land. "Lime is thus used when land is sown with wheat in the autumn to be followed by clover and grass-seeds in the spring. It is spread after the manure has been ploughed under, and the surface has been harrowed once. . . . Sometimes the lime is applied in the spring to a grass- or clover-sod which is ploughed under for maize."

Theoretically, it would seem to be better to plough under the lime rather than to harrow it in, since the sooner and the more intimately and completely the lime is brought into contact with the soil, the more thorough will its action be. All that is left uncovered until it has changed to carbonate of lime can never have opportunity to act as caustic lime. Generally speaking, rapidity is desirable when dealing with lime. No part of the work should be performed at odd moments. When the job has once been set about, the lime should be burnt, hauled, slaked, spread and ploughed under as speedily as possible.

Beside the economy of carriage, one great merit of laying out the quicklime in small heaps upon the field, and allowing it to slake there, rather than at the kiln or the farmyard, is that the powdery product can be distributed from the field heaps with less annoyance to the workmen than would be the case if it had to be carted. At the best, liming is a very disagreeable process, because clouds of extremely annoying dust arise from the fine powdery slaked lime to irritate the eyes and lips of the laborers.

Lime on Green Sward.

Sometimes lime is applied to grass-land, commonly when the grass is young, or to young clover, care being taken to have the material thoroughly slaked to a fine dry powder, and to spread it evenly. On fields that are adequately moist, the crop may sometimes be very considerably increased in this way. It is noticed that lime, like the potassic fertilizers, often favors the growth of leguminous plants, and that it tends to "bring-in" clover when applied to pastures. According to Philipar, neither red clover nor annual (crimson) clover can be grown with profit on the granitic soil of Britanny (France) until the land has been limed or marled.

As recently as 1860–70, the liming of permanent pasture-land has been extensively practised in southern Scotland. From 150 to 180 bushels to the acre is said to be an ordinary allowance, though sometimes more than 300 bushels are applied. It is said that upon deep soils, rich in vegetable matter and inclined to clay, lime has an extremely powerful effect in renovating the grass. "It at once cleans the surface, kills insects, decomposes decaying vegetable matter, and raises a close sward of sweet, nutritive grasses, including considerable quantities of white clover, and cattle will prefer the grass growing on the limed land." So, too, Lawes has said that "The first application of lime to moor-land, or to pastures which are deficient in lime, is often followed by a growth of white clover, so abundant as to have led some to the conclusion that the plant was spontaneously generated in the soil."

In southwestern England, also, lime was thought at one time to have a peculiar effect in sweetening and strengthening grass. One hundred bushels of lime to the acre before laying down the land to grass, and afterwards 50 bushels of lime every three years, applied as a top-dressing, have been found to serve well on pastured land.

Another account says: "Spread lime on old grass-land soon after mowing, at the rate of 160 bushels to the acre. Slake the heaps with a little water, spread the powder and brush it in while hot. The effects of this treatment may be seen for 15 or 20 years." Yet another account, relating to Westmoreland, says: "Lime has always been the favorite top-dressing for pasture-land, especially on the slate-rock formation, where it acts magically in producing a fine, sweet herbage. . . . The usual dose for a strong, healthy, rushy or benty pasture is from 200 to 300 bushels to the acre, an under-allowance being of little use. It is laid out from carts in convenient heaps, and generally left to 'sour' before it is spread. . . . One most important point is that lime must never be applied to wet land, or it will be thrown away. The beneficial effect is most strongly marked on newly-drained, sour, rushy land with a strong subsoil; and on this, or on mixed heaths and bents, the fine grasses and white clovers spring up plentifully after a good dose of lime. The first dose should always be a heavy one; after which the good effects will continue for 20 or 30 years. A second dose of lime never answers anything like so well as the first, and some artificial dressing is usually then resorted to."

It is noteworthy that after bone-meal came into extended use upon grass-lands in England, lime was much less used, in many localities, upon pastures and mowing-fields than it had been before. One reason for this change was, doubtless, that while both the lime and the bone encouraged the growth of clovers, the bone did additional service in that it really fertilized the land. In experiments with various fertilizers on pasture-lands in different localities, Voelcker observed that lime often had a decidedly beneficial effect upon the herbage, while at other times it diminished the yield, and appeared to have an injurious effect. He says: "There are, no doubt, soils upon which lime has been used with most beneficial effect upon the herbage. Indeed, I do not hesitate to say that, on soils utterly deficient in lime, it is impossible to derive the greatest benefit from the use of farmyard-manure or guano and other concentrated manures, unless they have been previously limed or marled. On the other hand, there are both light and heavy pastures on which lime has no effect whatever, for the simple reason that such land contains naturally a superabundance of carbonate of lime."

As a preparation for lawns, on non-calcareous soils, gardeners have often advised that lime should be freely used. As much as 200 bushels to the acre have sometimes been used for this purpose when the land was trenched; but usually the plan is to apply 50 bushels or so of lime to the acre at first, and to repeat the dressing every 3 or 5 years, until there has been added as much as 300 bushels to the acre. According to Joulie, writing of conditions which exist in France, it is always well to apply a certain amount of lime to grass-land, especially to permanent mowing-fields, at the rate of some 8 cwt. to the acre annually, put on in autumn immediately after the last mowing. The purpose of this lime is to prevent sourness and to promote the decay of dead organic matter, whereby the nitrogen that is contained in it is made available as plant-food. He urges that, even on calcareous soils, dressings of lime may be good for grass-fields, since meadows sometimes become sour at the surface, through the accumulation of dead organic matters, even in cases where the soil is highly calcareous at a depth of 8 inches. To his mind, it seemed absolutely necessary that all soils which naturally contain less than 5 % of lime should be dressed, before seeding down to grass, either with lime or with marl or with ashes from lime-kilns. Lime he held to be best, and he recommended that it should be used at the rate of from 16 cwt. to 2 tons to the acre.

Lime considered as Plant-food.

Looking at the question of the use of lime from the theoretical point of view, it is plain that a certain proportion of lime is necessary to the plant. Lime is a substance that can no more be spared than potash, or magnesia, or than phosphoric acid. Some of it must be present in the soil, or no crop can grow. But, in so far as the immediate requirements of plants in this sense are concerned, a few pounds of any lime compound to the acre would satisfy them, and there is already enough, and more than enough, lime in almost every cultivable soil. It is to be said, however, that several scientific observers have noticed that at the time of germination of many kinds of seeds, the organic matter of the seeds is put to better use, and is used up more completely by the young plants, when an abundance of some compound of lime is within reach of the plants. It has been found indeed sometimes that certain seeds either fail to produce plants when lime is lacking, or that they produce plants which are deficient as to size and vigor, very much in the same proportion as the supply of lime is inadequate.

According to Dehérain, lime is specially useful as an aid to germination when the seeds happen to sprout at temperatures lower than that which would be most suitable for them; and in some of his trials results as good as those got with lime were obtained by simply increasing the temperature at which the seeds were allowed to germinate. In his experiments, ulmate of lime gave better results than nitrate of lime, and the question suggested itself whether the organic matter of the ulmate might not have helped to nourish the young plants.

Lime is Abundant.

Lime is one of the most abundant of substances. It has been estimated that not less than one-sixth of all the rocks on the surface of the globe are limestones, and that the metal calcium forms as much as one sixteenth of the solid crust of the earth. Vast tracts of country are composed almost entirely of limestone, and there are wide ranges of soil that is wellnigh wholly calcareous. There are great beds of gypsum also here and there, and scarcely a rock can be found that does not contain lime as an essential ingredient. All the ordinary granitic rocks contain calciferous silicates. In the older part of Boston, the very waters of the wells are "hard," because they are charged with gypsum; and in many localities, where limestone abounds, all the waters are hard, from the presence in them of bicarbonate of lime.

It may often happen, no doubt, in sandy regions, and in soils which have resulted from the decomposition of certain sandstones, slates, and other rocks poor in lime, that neither the soil itself, nor the water which percolates through it, contains enough lime to serve as nourishment for plants; but in almost every such instance there is a still greater deficiency of other fertilizing materials, such as phosphoric acid and potash, than of lime, and the use, not of lime, but of some general manure, like that from the farmyard, will be indicated. In any event, if it were wished to give such a soil lime, it might be better to apply plaster of Paris, or bone-meal, or superphosphate, or some compost made with lime, rather than mere quicklime.

Income and Outgo of Lime.

This point can readily be illustrated by contrasting the amount of lime in ordinary soils, or even in the poorest soils, with the quantities of lime taken off in crops. It will be seen at once that cultivated soils commonly contain a great superabundance of lime over and above all that can possibly be needed for the mere purpose of feeding plants. Thus, if it be assumed that an acre of land taken to the depth of one foot weighs 3,500,000 lb., and that the soil contains no more than one-tenth of one per cent of lime, which, as the records of soil analyses show, is an extremely low estimate, there will still be no less than 3,500 lb. of lime to the acre. But in a crop of

18 bushels of wheat and 2,000 lb. of straw there are only some 6 or 7 lb. of lime.
12 bushels of peas and 1,200 lb. of straw, 28 or 29 lb. of lime.
120 bushels of potatoes and 3,000 lb. of tops, 20 lb. of lime.
375 bushels of mangolds and 6,000 lb. of tops, 25 to 28 lb. of lime.
In 5,000 lb. of clover hay there are 100 lb. of lime.

Moreover, wherever farmyard-manure is used, quantities of lime as considerable as those taken off in crops are commonly returned to the land, and in most commercial fertilizers also there is more or less of it. Voelcker's analysis of six months' rotted farmyard-manure shows 2 % of lime; that is to say, a single cord of such manure, even if it weighed no more than three tons, would carry to the land 120 lb. of lime. 100 lb. of guano contain some 10 lb. of lime; 100 lb. of bone-meal, about 27 lb.; 200 lb. of plaster, more than 60 lb.; and so on.

Lime Plants and Others.

It is a very old belief that certain kinds of trees and other wild plants flourish best on calcareous soils, while it is equally well known that other plants cannot abide the presence of much lime. In many regions, some species of plants occur so constantly on those soils which contain lime, while they are not seen on the non-calcareous soils of the locality, that their presence or absence is regarded as a characteristic indication of the nature of the soil.

In this country, Hilgard has insisted strongly on the fact that in the Gulf States some kinds of oaks, and such trees as the crab-apple, wild-plum, tulip-tree, honey-locust, juniper and some others, grow constantly on the fertile calcareous soils, while the pines proper are left in possession of the poor, non-calcareous land. On comparing a large number of analyses of soils that had never been subjected to cultivation, he concluded that in order that a soil shall be fertile enough to favor the growth of the lime-loving trees above indicated, there should be present in it not less than 0.1 % of lime if it be light and sandy, and not less than 0.25 % of lime if it is a clay loam. In heavy clay soils the percentage of lime should not be lower, he says, than 0.5, and it may rise advantageously to 1 % or even to 2 %. Beyond the last-named figure, it seems in no case to act more favorably than a less amount, unless it be mechanically.

As regards agricultural plants, it has long been a matter of popular belief that hops and sainfoin flourish best on calcareous soils, while sorrel and some other weeds disappear whenever the soil is well charged with lime. In many parts of Europe, the appearance of sorrel, oxalis, and certain other weeds in a field, is regarded as an indication that the application of lime or marl is needed. But according to Wheeler, lime so favors the growth of clover and other desirable plants, that they are thereby enabled to overcome the sorrel and crowd it out. He noticed, moreover, that while sorrel did not grow as well on limed land as on that which was unlimed, it grew far less luxuriantly on land dressed with lime and sulphate of ammonia than on land dressed with lime and nitrate of soda. In Ohio and other States, Lazenby has noticed that chestnut-trees are not seen growing naturally on soils which contain any considerable quantity of lime. He remarks also that many of the representatives of the heath family will not grow or even live for any considerable time on limestone soils.

Liming often improves Tilth.

From what has been said above, it will be seen that — with the exception perhaps of a few special crops — the farmer in applying lime to his land could hardly be justified in regarding it simply as a fertilizer of direct action. On the contrary, in seeking to explain the benefits derived from lime, special attention must be given to the physical and chemical actions of this substance upon the soil itself, and upon various constituents in the soil, as well as its corrosive action upon worms, insects and fungi, as will be explained directly.

Mention may here be made of a noteworthy fact of experience, that liming is often found to do good service on soils which already contain no small quantities of lime-compounds. According to Way, lime is uniformly applied with great success on soils of the London clay near Farnham. But this clay contains a considerable percentage of carbonate of lime in the shape of chalk fragments. Lime acts most beneficially also on the gault clay which contains a notable quantity of gypsum.

Much Lime is leached out from Soils in rainy Regions.

Attention has already been called (in Chapter VII of Volume I) to the fact that the waters of field-drains usually contain appreciable quantities of lime-salts, although they contain hardly any potash or phosphoric acid, whence it appears that in rainy regions lime must continually be leached out from the surface soil by rain-water — as a nitrate, a chloride, a bicarbonate or a sulphate — and carried in part into the subsoil and in some part out of the land.

As Hilgard has insisted, it is because of this leaching action that subsoils in Europe and in our Atlantic States are apt to contain more carbonate of lime than surface soils, and that the soils of valleys are often more calcareous than those of the adjacent uplands.

In many districts, the farmers are accustomed to make good this loss of lime by applying lime or chalk or marl to the land; but it is a curious and an extremely interesting fact that in arid regions where not enough rain falls to exert much solvent action, carbonate of lime tends to accumulate in the surface soils and is not removed therefrom. (See end of Chapter XVI in this Volume.) Practically speaking, the arid lands have all been marled naturally. As was just now said, analysis shows twelve times as much lime in good agricultural soils in our arid States as is found in the non-calcareous soils of the eastern coast.

Familiar examples of the leaching action in rainy regions are seen in the stalactites which form in the cellars and caves in limestone countries, and sometimes in tile-drains which have been laid in soils naturally highly calcareous or in those which have been heavily and frequently marled. After a number of years, it may happen that the tiles will become more or less incrusted with the lime-carbonate, and it is held to be inadvisable to use small tiles on such soils, lest they should be obstructed in places where the flow of water is habitually somewhat checked or impeded.

Lime changes Soil-texture.

There is no question, either that lime may or that it does actually exert a very powerful influence to alter the mechanical condition or texture of soils to which it is applied. Sometimes this alteration must be beneficial, and at other times detrimental; and this circumstance is of itself sufficient to explain why lime is esteemed in some districts and not in others.

A very little attention to the way in which lime acts in mortar will make this assumption clear. If a thick, smooth paste of slaked lime and water be spread thinly upon the surface of a stone, or upon a piece of wood, and left to dry there, it will be found that the film of dried lime adheres to the smooth surface with great tenacity; and since in the process of drying a good part of the lime has changed to the state of a carbonate, it cannot readily be washed away even. A familiar example of this adhesion is seen in ordinary whitewashing.

It is essential to the success of this experiment that the layer of lime should be thin; otherwise, it might crumble upon itself in drying. In case the paste be spread upon a porous solid, such as a brick, for example, instead of the wood or stone, it will be noticed that the lime adheres to it still more strongly than to the smooth surface, since some part of the layer has struck root, as it were, in the pores; and in case dry loam were taken instead of the brick, the adherence would doubtless be still stronger.

Now mortar is nothing more than a lime paste, into which so many little stones (grains of sand, that is to say) have been put that no more than a thin layer of lime shall be in contact with each one of these stones. But when a field is dressed with lime, the lime paste formed by the union of the lime with water must adhere to the particles of soil in a manner analogous to that now in question, and the physical character of the soil must be very much altered by this adherence. The power of the soil to lift water by capillary action will be changed, and in some cases it will be very much improved, while in other cases it will be diminished.

Marshall has said that before the use of lime became prevalent in the central valley of Yorkshire, much rye was grown on the lighter lands upon the margin of the Vale, while in the Morelands scarcely any other crops than rye and oats were attempted. But at the time he wrote, in 1787, rye was principally confined to the Moreland dales, and even there the alteration of the soils by lime had been such that wheat had become the more prevalent crop. As Hunter taught, long ago, "The great excellence of lime upon a sandy soil, is by mechanically binding the loose particles and thereby preventing the liquid parts of the manure from escaping out of the reach of the root-fibres. Upon clay the effect of lime is different, for by means of the gentle fermentation that it produces the unsubdued soil is opened and divided. . . As light sandy soils contain but a small portion of oleaginous particles we should be extremely cautious not to overdo them with lime, unless we can at the same time assist them liberally with rotten dung, woollen rags, shavings of horn and other manures of an animal kind."

The geological formation called loess, first by the Germans, but nowadays by everybody, affords a stupendous example of the binding power of lime. This extraordinary formation covers several hundred thousand square miles in Northern China, and larger areas in other parts of Asia. It covers an immense area in our own

Western country. In China it is occasionally 2,000 feet thick, and in Europe and America sometimes 150 to 200 feet thick. Now this loess is a calcareous loam, which is easily crushed in the hand to an almost impalpable powder, and yet its consistency is such that it will support itself for years in vertical cliffs 200 feet high. On close examination, it is found to be filled with minute tubular pores, which branch downward like rootlets, and these pores are lined with carbonate of lime. It is to these tubes that the loess owes its consistency and its vertical internal structure. In China, in particular, the loess districts are extremely fertile plains. They constitute the grain regions of Northern China, which have been cultivated for more than 4,000 years, apparently with very little manure. The porosity of the soil permits the elevation of nutritive matters from a very great depth, whenever a rain has established a moist communication with the ground-water.

Overliming.

In the North of Scotland it has not infrequently happened that peaty and moor-land soils, which are naturally light, have been "overlimed," as the term is; one symptom of the affection being that the land becomes too loose and open, so that it sinks under the foot and affords no proper support for the roots of grain-plants. The inference is, that the texture of the soil has been hurt, so that it is no longer in a good capillary condition, and cannot bring water to the surface readily from below.

On the rice-fields of Japan, applications of 5 tons of lime to the acre sometimes cause the particles of the soil to become so firmly cemented, either at the surface or a few feet below, that both the soil and the crop suffer injury. Water stagnates upon the land, cultivation becomes difficult, and both the straw and the grain of the rice-crop are brittle and of inferior quality. (Kellner.)

Flocculation by Lime.

Another kind of mechanical action, even more important than the foregoing, is found in the power of lime to cause the coalescence, or so-called "flocculation,"of the finest particles of soils into coarser granules. If a quantity of ordinary loam be washed with distilled water upon a filter until all soluble saline matters have been removed from it, or — better yet — if the loam be treated first of all with hydrochloric acid, to remove any lime which may have been contained in it, and then be washed with distilled water, the character of the loam — i. e. its condition of tilth — will be materially changed. On stirring some of the washed loam into a large volume of distilled water it will be noticed that while the heavier particles of earth settle out at once, many of the lighter particles will remain in suspension for a considerable time, and that the water will be left permanently muddy, or at the least cloudy. But on stirring into the muddy liquid a small quantity of a salt of lime, the suspended particles of fine earth will soon cohere to form flocks, which speedily fall to the bottom of the containing vessel and leave the liquid clear. This experiment, suggested by Schloesing, is a particular instance of a very general fact observed many years ago by F. Schulze, that muddy liquids can readily be made clear by adding to them lime-water and certain other chemical agents. Schulze noticed, in particular, that extremely minute particles of clay, such as will never settle in a mud-puddle, will, on the addition of small quantities of lime, bicarbonate of lime, or the like, speedily flocculate or coagulate into larger aggregations, which soon settle out and leave the water clear. The sediment thus obtained is of much looser, lighter character than clay or mud which has settled by itself, and this looseness of texture or friability persists when the sediment is dried.

Schulze's experiments and observations have been repeated both by Schloesing and by Hilgard, and it is now well known that lime has a very remarkable power to act in this way upon all extremely fine particles of matter, and thus to improve the texture of clays and silts and fine loams, such as would naturally be too muddy or cohesive. Not only does the presence of lime in a soil hinder the floating about of the colloid clay, but, as Schloesing has remarked, it tends to assure some semblance of permanence to whatever of good tilth may have been obtained by the operations of tillage.

Lime may Increase Permeability.

Again, there is in ordinary soils on an average about 50% by volume of open, "empty" space, which is divided up by a vast number of grains of sand and clay, but the manner in which this empty space is divided is of immense practical importance. It is essential in order that good crops may be grown that the open spaces in a soil shall neither be too large nor too small, and in many cases it is advantageous to treat a soil in such manner that the soil particles and the air spaces shall not be uniform but of uneven size.

In the case of a stiff clay, for example, where the small solid particles are so evenly distributed that the separate empty spaces between the grains are of nearly equal size, water will necessarily move about more slowly than would be the case after some of the fine particles have been flocculated and made to adhere to one another more closely and to the larger grains of sand also, for in this way some of the open, empty spaces will be made larger and others exceedingly small. Hence when lime is applied to a close, tight clay in which water moves but slowly, and flocculation occurs, many of the particles of clay are brought closer together and larger open spaces are formed in the soil. "In the clays of the Potomac formation in Maryland the grains are very evenly distributed, and the flow of water is so extremely slow that the soil is practically impervious to water. In such a soil a rapidly growing plant might perish for lack of sufficient water supply, when it had been shown by analysis that the soil contained a large amount of water. The movement of water would be so slow that the soil could not supply the plant with water rapidly enough for its need, and the plant would suffer for water as in a light, sandy soil." (M. Whitney.)

To illustrate the mode of action of lime on clay, Sachsse and Becker mixed intimately a weighed quantity of a heavy clay loam with 2% of quicklime, and packed the mixture in a wide glass tube, across the lower end of which a piece of lace had been tied. For the sake of contrast, another tube was charged with a similar quantity of the loam to which no lime had been added, and in each case the column of soil was made to be 15 cm. high. On pouring water into the tubes it was noticed that in the absence of lime the water penetrated the loam to a depth of but little more than 8 cm. in the course of 2.5 hours, and that the mud then became wholly impermeable. During the next day no water dropped from the bottom of the column of earth, although there was a layer of water 16 m. m. thick lying on top of the earth. But in the tube charged with the mixture of loam and lime, water passed through the 15 cm. column of soil in an hour and ten minutes, and thereafter it continued to drop regularly from the bottom of the tube. Of 61.2 c. cm. poured into the tube, 22.5 c. cm. passed out at the bottom, and 38.7 c. cm. were held by the soil.

In a similar experiment made with kaolin mixed with 2% of lime, water passed regularly and gradually downward through the tube, so that in the course of an hour and fifty minutes the whole of the kaolin was wetted. Of 40 c. cm. water that were poured into the tube, 19 c. cm. were caught as a filtrate. In the case of kaolin alone that contained no lime, the action of the water was not a little remarkable. It passed quickly into all parts of the kaolin, and a few drops of it even fell from the bottom of the column, but the mud immediately became impermeable, and the kaolin swelled to such an extent that the tube burst.

Loam is made Muddy by Washing.

It had often been noticed by experimenters, seeking to wash out from soils the soluble matters which are contained in them, that the first portions of wash-water flow off clear enough, but that the succeeding portions are cloudy from the presence of suspended matters, notably minute particles of clay. On encountering this difficulty Schloesing found that he could overcome it, at least for the soil he had in hand, by passing a current of carbonic-acid gas through the soil while he was washing it; and he concluded that the formation of bicarbonate of lime, by this device, was the cause of the filtrates remaining clear. Undoubtedly the bicarbonate does act in this way, but it is now known that carbonic-acid water by itself has the power to flocculate clay, and that as a general rule acids are highly efficient agents for accomplishing this purpose. Many saline substances have a similar power, though with the exception of certain acid salts — such as the sulphates and chlorides of iron and of alumina, superphosphate of lime, or the like — few of them act so quickly and so decidedly as caustic lime and the true acids, such as muriatic acid, for example.

Alum has long been used in eastern countries for clarifying muddy waters, and as it is now known sea-salt acts in this way to keep the oceans clear.

Lime Clears Muddy Water.

Schulze noticed that while lime and compounds of lime, acids of various kinds, salts of potash and of soda, carbonate of ammonia, and many other substances, acted to flocculate the particles of matter suspended in muddy liquids, ammonia-water had no power to do so. Schloesing corroborated these results, and noticed that turbid clay-water was precipitated immediately when one one-thousandth part of chloride of calcium was added to one part of the liquid, and in the course of a few minutes, when no more than two ten-thousandth parts of the chloride were added; but when the proportion of the chloride was reduced to one fifty-thousandth part, two or three days' time were required for the clarification of the liquid. He found that nitrate, sulphate, bicarbonate and hydrate of calcium acted like the chloride, and that magnesium salts were almost as effective as those of calcium. Potash salts on the contrary had to be used in quantities about 5 times as large as those of calcium in order to produce the same effect, and sodium salts were still less active than those of potash.

Similar results were obtained with muddy liquors prepared with loams; they could be clarified quickly by a few ten-thousandths of a lime salt, and a few hundred-thousandths were sufficient to precipitate the suspended matter in the course of 24 or 48 hours. Unlike the acids, alkaline solutions do not act to flocculate clay. Unless the solution of alkali be concentrated, it will not precipitate clay-liquor, but will favor the retention of the clay in suspension. No matter what the precipitant, as soon as the coagulated clay has been freed from the substance that threw it down, it regains its power of remaining suspended in water, and it can again be precipitated therefrom on adding lime.

Schulze found that 1 part of slaked lime in 20,000 parts of water was competent to clarify mud-puddle liquor. A quantity of milk of lime that contained no more than half of one per cent of slaked lime was sufficient to clear up a muddy liquor prepared by stirring 10 c. c. of clay into 100 c. c. of water. Numerous results of similar import have been obtained by other observers. It has been noticed repeatedly that while bicarbonate of lime, as well as various saline matters and acids, are highly efficient agents for clarifying clay-water, small quantities of the alkalies and alkaline carbonates tend to prevent the flocculation and precipitation of suspended clay. According to M. Whitney, the opposite effects produced by the soluble alkalies and by lime may readily be shown by stirring some clay in water to which a trace of ammonia has been added, and putting a drop of the turbid liquor under the cover glass of a microscope. It will be seen that the fine particles of clay cannot come close together, or that they are actually repelled. But on adding a trace of lime, the particles of clay will gather together in light flocks, which not only approach each other, but are held together by some force.

Puddled and Granulated Soils.

As was explained under the head of Tillage, there are certain processes in the arts where the object is to make particles of clay or earth as fine and adhesive as possible, as in the processes of tamping, puddling, and kneading. But in agriculture it often happens that it is desirable to do away with the tamped, puddled, adhesive condition into which soils are apt to fall, and, for the reasons above stated, lime is one prime agent for effecting this result.

The importance of lime in this regard may be shown by a rather striking experiment of Hilgard's, as follows: "Let any clay or tough clay soil," he tells us, "be worked into a plastic mass with water and then dried; the result will be a mass of almost stony hardness. But on adding to some of the same paste no more than half of one per cent of caustic lime, a diminution of plasticity will be obvious at once, even while the clay is wet, and, on drying, the mass will fall into a pile of crumbs at a mere touch." Thus it is that by liming clay soils they may be made "warmer," "mellower," and of better tilth.

Schloesing found that lime-water was more effective than any other calcium-compound for coagulating mud-puddle liquor, i. e. clay-water; and both he and Hilgard find that no other chemicals are so powerful in this respect as the lime-compounds. Hilgard made carbonic-acid gas bubble through a magma of limed clay for 24 hours to destroy the causticity of the lime, but the plasticity of the clay was not restored, not even after the mass had dried, for in this case nothing was done to break down the flocks.

Once get the fine particles granulated, no matter by what means, and they will stay so until they are subjected to kneading, tamping, puddling, or washing. This result agrees with practical experience. On some kinds of soils farmers find that the "lightening" effect of a liming lasts for years, and is never entirely lost. So too, it is known that marling produces similar lightening effects to lime, though the action of the marl is, naturally enough, weaker than that of the lime. The influence of the marl will depend on that of bicarbonate of lime formed by the solvent action of the carbonic-acid water in the soil upon the carbonate of lime in the marl. Whereas, in case land is limed, it is to be remembered that, since caustic lime itself is somewhat soluble in water, the solution of it (lime-water) will soak into the soil in all directions around each particle of solid lime, and so extend the limit of its influence.

It is an interesting experiment to put a handful of noncalcareous clayey soil upon a funnel and cause a slow stream of rain-water to flow steadily upon it. For a time the water which passes through the clay will be seen to drop bright and clear from the funnel-tube, but after a while the drops of filtrate begin to appear muddy, and the mass of clay finally becomes so muddy and adhesive that no water can pass through it and the funnel is choked. But if, at the moment when the drops of filtrate first begin to be muddy, some lime be sprinkled upon the surface of the clay, the tendency to form mud will be checked, a clear filtrate will again pass through the funnel tube and will continue to do so until all the lime has been dissolved and washed away.

Thus it is, when rain falls continuously on unlimed clay-land, that the water soon ceases to be absorbed, because the clay at the surface of the soil has become puddled. In case the field is flat, mud-puddles will form upon it; while from hillsides streams of turbid water will flow away and carry off large quantities of the finely-divided soil. It is only long after the rain has ceased, and after enough moisture has evaporated from the surface of the soil to induce a strong capillary movement from below upward, that saline matters are brought to the surface in sufficient quantity to mitigate in some degree the plasticity of the clay, and to enable the soil again to permit some rain-water to soak into it. (Aitken.)

Action of Lime on Clay.

A more methodical method of experimenting to illustrate the effect of lime on clay has been adopted by Pearson. He dried and pulverized three different clay soils, sifted them to the same degree of fineness, and mixed portions of them with quicklime, which was added to the amounts of 0.25, 0.50, and 2.5 % respectively. These mixtures of clay and lime were made into a paste with water and were then dried, ground and sifted, as the clay had been. Definite quantities of the materials were carefully placed in glass tubes, pains being taken to bring all the samples to the same state of compactness in the tubes. The powders were filled into the tubes to a depth of two inches, each of them was covered with half an inch of sand, and a gentle stream of water was made to flow into the tubes until there was a column of it two inches deep resting upon the sand. Finally, the time required for the water to disappear below the sand was noted. It appeared in every instance that the water percolated much more rapidly through the limed clays than through the crude clay. The following table gives the rate of percolation as taken from the average results of three trials with each of the samples.

Material operated upon.	Lapse of time during the percolations.								
	Sample No. I.			Sample No. II.			Sample No. III.		
	days.	hrs.	min.	days.	hrs.	min.	days.	hrs.	min.
Clay, without any lime . .	6	4	17	12	11	28	26	19	0
Clay, with 0.25% of lime .	0	12	42	10	2	45	7	23	15
Clay, with 0.50% of lime .	0	9	57	5	6	30	2	12	30
Clay, with 2.5% of lime . .	0	2	55	0	8	20	0	7	0

In calling attention to the striking difference between the 6 days and more that were required in order that 2 inches of water should percolate through 2 inches of the crude clay numbered 1, and the half day which sufficed for the completion of the same amount of work after the clay had been mixed with a quarter of one per cent of lime, Pearson remarks, "Had the test consisted of pouring 2 inches of water upon wet soil instead of upon dry, the contrast would have been still greater." He notes also that soil No. 3, which in its crude state required from 23 to 31 days for 2 inches of water to percolate through it, allowed the water to pass in seven hours after the soil had been mixed with 2.5 % of lime.

Importance of Lime on Clays.

The improvement of the texture of clayey soils that results from the use of lime, and of lime carbonate, is a practical fact of the very first importance, for such soils become comparatively open, mellow and porous, and much less apt than mere clay to be baked into hard crusts or clods on drying. Thanks to the fact that water can now percolate through them instead of being held too tenaciously, they lose much of their former coldness and become warm, both because the excess of water can drain out from the soil, and because air can enter the pores to take the water's place. Instances are not wanting in the history of agriculture where regions of sticky, clayey soils have become fertile on the discovery that the unfriendly soil could be made better by means of lime or marl. The benefits derivable from such amelioration may readily be conceived on considering how difficult it is, generally speaking, to cultivate clays, and how much trouble has to be taken in order that young trees may be made to grow on clays that are somewhat refractory. According to Evelyn, "It is observed that oaks which grow in obstinate clays are long before they come to any considerable stature (for all sorts of clay is held but a step-mother to trees), but in time they afford the most excellent timber, having stood long and got good footing." G. B. Emerson, in his "Report on the Trees and Shrubs of Massachusetts," has remarked that "the northern and southern sides of Boston are not essentially unlike in their natural features; yet the hills of Brookline and Roxbury, capped with hickory, and whose sides are clothed with oaks and pines, give the impression of a rich and happy country, of which only pleasant memories are carried away, while the bare hills of Chelsea suggest images of bleak and barren desolation." This statement may be emphasized by adding, that the bare Chelsea hills, like those of the neighboring bare islands in Boston Harbor, are composed of stiff, unfriendly, glacial clay; which, though easily "cleared" by the first "planters," and still esteemed to be good land for grass, is not well suited for the growth of young trees. The wooded heights of Roxbury and Brookline, on the contrary, are for the most part gravelly or rocky.

The geologist, J. D. Whitney, has insisted once and again that the extreme fineness of many prairie soils at the West is the chief reason why these prairies were bare of trees when first discovered.

Schuebler long ago called attention to certain shaly marls rich in clay, abundant in Wurtemberg, which occur in the form of fine shaly gravel when freshly dug up, and retain this structure for a long time when left at rest, even when exposed to repeated changes in respect to heat, cold, wetness and dryness. In this natural state they are regarded as dry, loose, so-called hot earth, which is on this last account often applied to vineyards for their improvement. But after weathering for 2 or 3 years — or when reduced to fine powder by long-continued rubbing — this gravelly marl acquires all the physical properties of a heavy, cold clay-land, through which moisture can pass only with difficulty.

Some Silts need to be Limed.

Wicke, in publishing analyses of several very finely-divided clayey silts from the Oldenburg marshes, which, though of excellent chemical composition, are notoriously infertile, — so much so, indeed, that the farmers when ploughing take particular care not to turn them up from the subsoil, — admits his inability to explain their barrenness, unless it depends on the fineness of their particles, and their consequent plasticity and liability to form stone-like clods in drying. Some of these soils have been improved by dressing them with gravel, and others by means of lime and by marl. I have myself observed, in pot experiments, on attempting to grow plants in pipe-clay admixed with sand, that the fine particles of the clay seemed actually to clog the pores of the plant-roots, and prevent their development. (See Bulletin of the Bussey Institution, 1884, II, 309.)

In general it may be said that the plasticity and cohesiveness of clay are obnoxious to vegetation, unless these qualities have been in some way mitigated. Healthy plants cannot be grown in soils so compact and moist that neither air nor warmth can penetrate them. But experience has shown that lime is one very useful agent for ameliorating the too great tenacity of clay. In some parts of England, the quantity of lime to be applied to clay-land was specified in the agreements between landlords and tenants. One form of contract was that the fallow fields should receive 100 bushels of lime and 12 cubic yards of manure to the acre. It was considered to be good practice to spread the manure on the land before the stubble was ploughed, in order that the land might be kept drier and more open during the winter. Sometimes the lime was hauled on when the land was frozen and made into heaps about the field. After having been spread, the lime was well harrowed, it having been thought a matter of much importance that it should be distributed through the soil as completely as possible.

It has been maintained by some writers, and denied by others, that plants often vegetate more rapidly in good soil that has been limed than upon that which has received no lime; that is to say, some persons have urged that the time required for a crop to grow and ripen is usually rather shorter on limed land than on that which has not been limed. It is evident that the idea might be generally true as regards unfriendly clays, because of the improved mechanical condition of the clay whereby it may become comparatively "warm" as well as mellow.

Meanwhile, it should not be forgotten that — no matter how important lime may be for improving heavy clays — there must be some soils, containing small proportions of clay, where lime might do serious harm by coagulating the clay and thereby changing the capillary power of the soil and impairing its capacity to retain moisture. As will appear in the next paragraph, this remark would apply specially to some kinds of light soils that contain but little organic matter.

Importance of Lime for Sands.

On the light, sandy soils of southern Maryland, lime is considered to be "the best fertilizer," provided there is enough organic matter in the soil "for the lime to act upon," otherwise it will "burn out the land." Where lime is applied in that region, clover or some other green manuring, or stable-manure, are considered to be necessary adjuncts. It has been shown by M. Whitney that the merit of this combination of lime and organic matter depends on its power of making the sandy land much more retentive of moisture than it was naturally. He found by experiment that, "An inch in depth of water will pass through six inches in depth of the coarse sandy subsoil of the pine-barrens in about five minutes. A little lime added to this sand will slightly diminish the time necessary for the water to flow through. A filtered extract of stable-manure, without the lime, passes through without materially affecting the rate of flow; but if the lime is first added to the soil and then the solution of organic matter is passed through, the organic matter is precipitated from the solution within the soil by the lime, in light, flocculent masses, and the liquid comes through quite colorless, and the rate of flow becomes slower and slower, until this coarse sand may become almost impervious to water."

As has been stated already under the head of Fish-Waste, and as will be set forth more in detail under Sewage, many organic matters can be thus coagulated and precipitated from their solutions by means of lime.

In other experiments, made upon coarse, sharp building sand, Whitney found that filtered barnyard-liquor might pass unaffected through the sand, but in case lime (or certain other fertilizing substances) were added to the sand, the organic matter of the manure was precipitated and retained, as in a soil proper. In case the uppermost inch of sand was mixed with lime and treated with the dung-liquor, it speedily assumed the dark color of loam resting on a light sandy subsoil, with a sharp line of demarcation between them. In Whitney's own words, "As a matter of fact, there is no soil which responds so readily to lime as these light sandy lands, when sufficient organic matter is added, or is present, for the lime to act on. . . . To change the physical condition and texture of a soil so as to make it more retentive of moisture, there are two possible lines of procedure which may be clearly recognized and defined. The soil-grains may be pushed further apart, not necessarily so that the volume of empty space will be increased, but that the fine grains of clay shall be pushed further out from the larger grains of sand, so that the grains will have a more symmetrical arrangement within the soil, or, if the grains have already such an arrangement as to give the full value to the clay, this skeleton structure can be filled in with organic matter by precipitation of organic matter within the soil."

Liming destroys Insects, Worms, and Fungi.

While carbonate of lime is helpful for nitrification, lime proper, i. e. slaked lime, is regarded as a cure for some hurtful fungi. The liming of seed-grain to destroy the fungus which causes "rust" or "smut" has long been usual. The use of lime upon turnips, as a check to the finger-and-toe disease, has already been mentioned; and I can myself bear witness that I have grown exceptionally fair and smooth rutabagas during three consecutive years upon limed land at the Bussey Institution, though no farmer in the vicinity would venture to try to grow turnips year after year on any one field, because of their liability to the disease called "club foot."

There is corroborative evidence, it should be said, which tends to show that the lime really acts in these cases to destroy the pests. Thus, Gillespie, writing of the County of Dumfries in Scotland, has said: "Lime put upon stubble or sod-land has often been found effective in guarding against the disease called "finger-and-toe." One promoting cause of the disease is giving affected turnips to sheep or cattle upon sod-land or stubbles which are about to be ploughed for growing a turnip crop. I am acquainted with several persons who, after lengthened and careful observations, have never known this to fail in bringing on the disease."

It has been remarked also that in the County of Aberdeen in Scotland turnips are more subject to finger-and-toe than they are in Norfolk in England, although both these counties are composed chiefly of light turnip-soils, and although the crop has been cultivated twice as long in Norfolk as in Aberdeenshire and in a much shorter rotation. But in Norfolk the climate is rather dry and the sky is measurably bright, and the conditions are not favorable for the accumulation of organic matter in the soil; while in Aberdeenshire the climate is moist and cloudy and favorable for the accumulation in the soil of the organic remains of plants, "some kinds of which — and notably that left by turnips — act injuriously upon succeeding crops."

Evershed, writing in 1853, has said, of the county of Surrey (England), "Liming is now chiefly valued as a preventive of club in turnips, for which purpose its good effects are very remarkable, and are frequently to be seen after the lapse of many years. There are instances, on the loams of the greensand, of excellent crops of turnips being grown on land which had been limed twelve years before, while the club has been destructive on similar soils and even in the same field where the lime has been omitted.

In an account of Oxfordshire, England, written in 1855, it is said, "Lime is used on land recently broken up and on peaty soils, and also on the light redlands; but it is principally applied as a dressing to cure the "club-root" and "fingers-and-toes" in turnips. Some land requires 80 bushels of lime every 8 or 12 years in order that roots can be grown upon it with any certainty. Not only do turnips suffer, but the club-root even attacks mustard and rape. The lime is applied to the land, while yet hot, as soon as it is slaked. A man follows the plow, sowing the lime at the bottom of the furrow, which is covered over by the next turn of the plow to a depth of 3 or 4 inches. If applied in this manner it is a certain cure for this troublesome disease, and has never been known to fail."

In this country both Henderson and Waring have reported the successful growing of cabbages and rutabagas on limed land. Waring even obtained excellent results on spreading air-slaked lime from a broadcast sower upon heavy moist land in the proportion of a single barrel to the acre.

A writer on the agriculture of Staffordshire, England, says that, on strong, heavy land, the usual dressing of lime is from 3 to 5 tons to the acre. Less of it is used on light land, but it is applied on turnip-land at least once in 12 years at the rate of 3 or 4 tons to the acre. The universal use of it may be partly attributed to the necessity of a corrective upon land that has been kept for several years as pasture in grass and clover. The lime acts as a medicine, not as a manure. It checks slugs, destroys grubs, and prevents club-foot in cabbages. Wheat grown on limed land is brighter and the straw stiffer than if no lime had been applied.

Lime favors Healthy Growth.

Professor Voelcker has stated the matter as follows: "Every [British] farmer knows how essential lime is for the healthy growth of every kind of produce. On soils destitute of lime, most crops, and especially green crops, are subject to disease, and 'root-crops' are apt to fail altogether on such land, even if it has been liberally manured with dung or guano. Up to a certain stage, grain and roots grown under such conditions appear to thrive well, but as the season advances they sustain a check, and at harvest-time yield a miserable return. The cure for such failures, which are not uncommon where poor sandy soils prevail, is a good dose of lime or marl, and then, and only then, dung or guano may be applied to the greatest advantage. The most liberal application of farmyard-manure of the best quality never produces so beneficial and lasting an effect on poor sandy soils as when they have been previously well marled or limed."

While it is not improbable that some part of the good effect of lime, in such cases as the foregoing, may depend on its acting to mitigate the natural sourness of the land, it is still to be inferred that much of the good done by the lime may really be due to the destruction of insects and their larvæ, as well as earth-worms and worms of other kinds, and fungi of various sorts. Indeed, lime-water, lime, and mixtures of lime and salt (or, better yet, of lime and muriate of potash?) are often purposely used by gardeners for destroying slugs and worms; and there are good reasons for believing that lime might often be applied to the soil with advantage in farming practice also, on this account.

It has sometimes been argued that lime should be applied with a liberal hand, when the main purpose of it is to free the soil from worms and insects. Thus it has been said that if no more than 3 or 4 tons to the acre are harrowed in, some insects may escape destruction because there is not lime enough to mix with every part of the earth; but if as many as 7 or 8 tons of the lime were to be well worked into the soil, a thorough clearance would be made.

It must always be borne in mind that slaked lime is appreciably soluble in water, and although this "lime-water" cannot be supposed to continue to exist very long in the soil after its formation, in view of the large quantities of carbonic acid which the pores of the soil contain, the liquid is still so destructive to animal life that there is good reason to believe that, while it does last, its action in this way may often be of considerable importance.

Lime versus Slugs.

Lime has sometimes been applied in England in the state of quicklime, not merely for the sake of destroying insects and worms, but for the improvement of the land, in the belief that, by using it in this state, the decomposition of vegetable matters in the soil may be more speedily accomplished than in any other way. To this end, well-burnt lime was piled up rapidly in winter on a dry part of a fallow field, in very large, well-rounded heaps. The first shower of rain that fell slaked enough of the lime at the surface of the heaps to form a protective crust which hindered the interior lime from falling too rapidly to powder. After the land had been ploughed and prepared for sowing in the spring, this caustic lime was spread in dry weather at the rate of from 100 to 175 bushels to the acre, and was well worked into the soil by harrowing.

For the purpose of destroying slugs, it is customary, in some parts of England, to sow very early of a damp morning small quantities of lime or of salt upon clover-fields and bean-stubbles before ploughing them, as a preparation for grain. When this work has been omitted, and slugs are found destroying the wheat-blade in autumn, lime is sown as a top-dressing, but this plan is not so efficacious as the other, since those slugs which happen to be lying under the furrows are protected from the lime. It is desirable that the lime or salt shall actually fall upon the slugs, in which event they perish. A good dressing of fresh slaked lime is usually recommended. It is said that the moment the hot lime touches the slug he throws off his outer skin, and that the next particle which reaches him destroys life. But Cobbett insisted strongly that actual quicklime, in very fine powder, should be used for this particular purpose. He says: "An effectual way to destroy slugs is to sow hot lime in dust and not slaked. The slug is wet; he has hardly any skin; his slime is his covering; the smallest dust of hot lime kills him; and a few bushels to the acre are sufficient. You must sow the lime at dusk, or after dark, or before daylight, or just after a rain, for then the slugs are sure to be out; and the process should be repeated several times. . . . Put the lime in a coarsish bag, much larger than is necessary to hold the quantity, and after nightfall or before sunrise, in the dew or on the moist ground, go over their haunts, shake the bag and let the fine powder fall upon the ground; some little particle will fall upon every slug that is abroad, and every slug that is touched with the lime will die. If rain come it will destroy the power of the lime, and then it will be necessary, perhaps, to repeat the remedy several times. Slugs come after a crop that has long afforded a great deal of shelter from the sun, such as peas and vetches. In gardens, they are nursed up by strawberry-beds and by weeds, by asparagus beds, or by anything that remains for a long time to keep the summer sun from the earth."

Lime favors the growth of the Potato-Scab Fungus.

An exception to the destructive action of lime on fungi is seen in the case of the fungus (Oospora Scabies of Thaxter) which causes "scab" on potatoes and sugar-beets. It was noticed by Thaxter, in his experiments, that more scabby potatoes occurred in those hills the earth of which had been mixed with broken plastering and cement than in others, and that these materials manifestly exerted a very decided influence upon the virulence of the disease. As has been said in another chapter, several observers have noticed that potatoes are apt to be scabby when wood-ashes have been used as a fertilizer; and Wheeler has shown, by careful experiments, that it is the carbonate of lime in these materials which is harmful. In one word, he finds that carbonate of lime tends most decidedly to increase the scab of potatoes.

Moreover, the percentage of scabby potatoes is increased by the application of any compound of lime from which carbonate of lime will naturally be produced in the soil; and the malign influence of the lime-carbonate was still apparent and paramount when considerable doses of carbonate of potash or carbonate of soda were put upon the land, together with the lime. Sugar-beets, also, grown on limed land previously infected with the scab fungus, were very badly scabbed. But since the application of slaked lime to acid soils, such as are common in New England, not only increases the yield of potatoes but the percentage of large-sized tubers also, it may well be true that the use of lime might be economically advantageous in case only one crop of potatoes was to be grown, for the effects of the scab are not usually serious in the first year, provided the seed potatoes are free from the scab, or have been freed from it by means of corrosive sublimate.

Gas-Lime.

The spent lime of gas-works — which has served to remove from illuminating gas carbonic acid, sulphuretted hydrogen, and other compounds of sulphur — would doubtless serve particularly well for destroying insects, slugs and worms, and the best methods of applying it to this end should be discovered. Fresh gas-lime contains various sulphuretted and cyanogen compounds which are obnoxious to living things. When left for some time in contact with the air, the noxious sulphur compounds are converted to harmless gypsum, and the material may then be regarded, practically, as a mixture of carbonate and sulphate of lime. But it is apt to be contaminated with more or less coal-tar, which is a substance highly injurious to plants. Were it not for the risk that harm may be done by the tar (and by cyanogen compounds), weathered gas-lime might be made to serve useful purposes upon many soils; notably on stiff clays, to lighten them; on light, sandy loams, to give them solidity; and upon sour, peaty soils, to correct the acidity.

In point of fact, gas-lime is freely used in some parts of Holland, on clayey soils, to which it is applied at the rate of 200 or 230 bushels to the acre. According to some English farmers, fresh gas-lime may be safely applied in the autumn, at the rate of from 80 to 180 bushels to the acre, to land upon which root-crops are to be grown the next year; but harm has often been done by applying fresh gas-lime to grass-land. Composts prepared by mixing gas-lime and loam, and leaving the mixture to stand for some time, have often been found to be useful on light soils. It is not improbable that gas-lime might serve well enough for neutralizing sour humus, as a preliminary to the making of dung-compost. Numerous analyses of gas-lime have been published, but from the nature of the case it would be surprising if the figures of any two of them should closely agree. The following analysis by Adolph Mayer may serve to give a general idea of the composition of this substance: —

Water	30
Hydrate of lime	33
Carbonate of lime	17
Sulphate, sulphite and hyposulphite of lime	20

beside traces of sulphide of calcium, of sulpho-cyanide of calcium and of ammonia.

Liming corrects Acidity.

Quicklime has long been esteemed as a means of correcting the acidity of sour land, such as that of moors and bogs, which contains large quantities of free humic acids, and that which is uncultivable because of the presence of ferrous sulphate. In some regions, where even upland soils have a tendency to become harsh and sour, rather than mild and mellow, applications of lime have often given highly satisfactory results. In the words of Gasparin, "At the same time that acid-plants (such as sorrel) disappear, the yield of cereal grains is doubled, and the land becomes able to produce wheat in place of rye, and to bear forage crops of leguminous plants." It may here be said, yet again, that cultivated soils need not necessarily exhibit an alkaline reaction, though it is perhaps desirable that they should do so. It is to be presumed that land is at its best when it contains enough bicarbonate of lime that nitrification shall be constant and speedy, though granitic soils are met with occasionally, the waters of which are faintly alkaline from the presence of the bicarbonates of potash and soda. In non-calcareous regions, soils are apt to exhibit a slight acid reaction, though they are sometimes neutral to test-papers, and it may well be true that the importance of farmyard-manure for such soils, as in the vicinity of Boston for example, may depend in some part on the power of the alkaline manure to mitigate or correct the soil's acidity. It is probable, withal, that the high esteem in which ashes and leached ashes are held in many parts of New England may be due to their ability to correct acidity. But it is to be remembered that experience with water-culture has taught that slightly acid solutions are not unfavorable for the growth of plants when a sufficiency of food is present, though there is abundant evidence to show that any excess of soluble acids in the soil would be highly detrimental. The acid would injure the plants directly, and destroy the micro-organisms which regulate the fermentation of humus, as well as dissolve out iron compounds to poison both microdemes and crops. Such acidity may readily be corrected by lime, and the good effects of lime upon sour meadows in particular, may justly be credited to neutralization of their acidity. One noticeable effect of lime in such cases is the destruction of plants that thrive in bogs; the inference being that the lime has neutralized the chemical substances which such plants can, and English grasses cannot, support, and has so given the latter opportunity to grow.

There can be little doubt that many soils in New England are more strongly acid than is desirable. Wheeler, in Rhode Island, has noticed that beets in particular are apt to suffer from this natural acidity, and that, while the growth of oats, rye, maize, potatoes and millet may not be seriously affected, these crops would nevertheless be benefited by the application of fertilizers competent to neutralize the natural sourness of the land.

One way of determining whether a soil is acid consists in putting a weighed quantity of the earth, together with some carbonate of lime, into a confined volume of water, and noting upon a manometer the amount of pressure produced by the carbonic acid which is set free when the mixture is agitated. Conversely, the amount of lime-carbonate in a soil may be determined by putting a quantity of the earth, together with some powdered tartaric acid, into a confined volume of water, and measuring the amount of pressure produced by the gas which is disengaged.

Action of Lime on Humus.

Beside its power of coagulating organic matter, lime may act to hasten the decomposition of organic matter in the soil, and, as has been said before, it may serve to decompose the inert nitrogen compounds of humus. This effect is probably one of the most important of those produced by lime. Townsend has mentioned the case of a Welsh farmer, whose land had been a bog before it was drained, and consisted principally of dark-colored vegetable mould, much of which was actual peat, who found lime to be an excellent manure. He was accustomed to put most of his stable-manure upon mowing-fields, and to use only lime for wheat, and in this way he obtained very abundant crops. He had two lime-kilns constantly burning for his own use. Townsend remarks that "on this land I have counted 60 grains [of wheat] to an ear, not picked and culled out of many others as being longer than the rest, but taken by handfuls at random. . . . On this land, lime as a dressing was particularly apt, because, as we know, it hastens the putrefactive process, and promotes the dissolution of vegetable substances, converting them quickly into vegetable mould." So, too, Moreul, in describing the cultivation of clover, for seed, in France, has said, "On applying lime to sour, moist, peaty land, such admirable results have been obtained that lime has been called 'the best of manures.'"

The action of lime in such cases is manifestly analogous to its action in the compost-heap. There is doubtless at first a certain corrosive effect tending to break down the mechanical cohesion of the particles of peat and to break up the chemical compounds which the peat contained; there is neutralization of the sour humic acids, if they were present; and above all, the soil is made alkaline enough to permit the active growth of microscopic organisms which act as ferments upon the inert nitrogen compounds in the humus, and which may change a good part of this nitrogen into forms available as plant-food.

Lime may Expel Ammonia from Rich Land.

Some small part of the good effect produced by the lime may be attributed directly to the formation of ammonia from the inert nitrogen compounds in the humus under conditions favorable for the speedy nitrification of this ammonia. Boussingault has shown by an elaborate research that when slaked lime is mixed with good garden or farm loam, there is a constant slow production of ammonia so long as the lime remains in the caustic condition, and several other observers have noticed that no inconsiderable quantities of ammonia are sometimes actually lost in this way, by exhalation, from fields which have been heavily limed.

It follows from these results that it can hardly be advisable to lime land at the moment when that land is to be dressed with barnyard-manure or any other fertilizer rich in ammonia, lest too much of the ammonia should be lost through volatilization. In case both lime and farm-manure were to be applied to one and the same crop, it might be best to plow under the lime in late summer or in autumn, and not to spread the manure until the next spring.

Many of the results obtained by Boussingault have been given already in Volume I., under Nitrification. An additional example will be found in the following statement, which relates to a dark-brown, compact peat that contained 2.2 % of nitrogen, no nitrates, and 0.02 % of ammonia.

1,000 grm. of the powdered peat left during
5 weeks admixed with 100 grm. of hydrate of lime gained 0.137 grm. of ammonia.
13 weeks admixed with 100 grm. of hydrate of lime gained 0.124 grm. of ammonia.

The peat was then made less compact by mixing with each kilo. of it 4 kilo. of sand and 400 grm. hydrate of lime.

1,000 grm. of this mixture left during
1 month, gained 0.332 grm. of ammonia.

One noteworthy result of Boussingault's tests is that the quantity of ammonia developed is not proportional either to the quantity of lime employed or to the amount of organic nitrogen in the soil one hundred parts of lime acting on the peat above mentioned, which contained more than 2 % of nitrogen, produced little more than 0.1 part of ammonia, while some of the loams examined gave 0.3, 0.4 and 0.8 parts.

Sometimes very small applications of lime gave amounts of ammonia which were out of all proportion large as compared with the amounts of lime. Thus, in two of his experiments where 3 grms. of lime were mixed with 1,000 grms. of loam,— i. e. a quantity which would have been a mere sprinkling on a field — as much as 2.33 and 4.00 parts of ammonia for every 100 parts of the lime employed were developed in the course of a week. But when larger amounts of lime were applied it was unusual to get as much as 0.8 lb. of ammonia for each 100 lb. of the lime. As the mean result of his experiments, 0.033 grm. ammonia to the kilo. of loam was quickly developed by the lime, and although this amount is but small, it is decidedly larger than the quantity of ammonia ordinarily contained in the best loams in northern countries. In point of fact, in these experiments, the act of liming had the effect of doubling the quantity of ammonia in the soil. For there was found on the average no more than 0.017 grm. ammonia to the 1,000 grm. of good French loams, although in fertile loams from South America, as much as 0.063 grm. to the kilo. were obtained on the average.

Destructive Action of Lime.

In many cases the corrosive disintegrating action of the lime, and the fermentations which may precede nitrification, are to be regarded as highly important; as when lime is used as an adjunct to green manuring, where a crop or sod-land has just been plowed under, or when applied to new land, or to land so foul with weeds that a sort of green manuring has been obtained by ploughing it. In order to get the full effect of the caustic lime in such cases, it should be well worked into the soil when freshly slaked, and before any seeds are to be sown.

Kellner, in Japan, on contrasting the action of lime on slightly moistened upland soil, with which some organic matter had been mixed, with its action on wet swamp-land similarly charged with organic matter, found that while the lime hastened the decomposition of the organic matter in both cases, the action was much more pronounced on the dry land than on that which had been kept wet. While the dry land lost 13.58 % of its organic matter in the course of six weeks, the swamp-land lost only 5.85 %. The same soils without the addition of lime lost 3.24 % and 2.21 % of their organic matter, respectively. It is perhaps this tendency to destroy organic matter which makes the too frequent use of lime pernicious. To it is probably due in part the old-world proverb, "Lime enriches the father, but beggars the son."

It must always be remembered, however, that, when the use of lime first became general in Europe, the farmers were prone to believe that it could be employed as a substitute for stable-manure. Hence a tendency to abuse in using it. No doubt many a field has been reduced to the verge of sterility by applying lime until the entire store of available nitrogen and phosphoric acid and potash had been used up. All the evidence teaches that lime is no substitute for manure; it is a mere addition or reinforcement which may occasionally be employed with advantage. Years ago, when lime was the only commercial fertilizer accessible to the farmer in the interior of Europe, he thought himself compelled to use it at every pinch; but now that many other kinds of fertilizers can be bought, the tendency to use lime injudiciously has been greatly lessened.

The corrosive power of lime explains the danger of allowing seeds or young plants to come in contact with too much lime. Davy found long ago that it was an easy matter to kill grass by watering it with lime-water. An English farmer, Mr. Carrington, in an article "on the advantage of converting cold clay arable land into permanent pasture," has written as follows: "No person who has not had experience will appreciate fully the difficulty and tediousness of the operation of converting into really good turf, poor, strong [i. e. stiff] land which has been constantly under the plough for generations, and in which every bit of vegetable matter has been used up by the practice of having periodical dead fallows dressed with lime. . . It is only by repeated liberal applications of manure that such land can be made into productive turf."

Yet the fact is indisputable that lime may be of vast importance for improving humus in many cases. Thus Fleischer, in describing certain high-lying German moors (heaths), which have long been cultivated by the method of burning, points out that extraordinarily favorable results are often got by means of dressings of quicklime or of marl in cases where without the lime abundant applications of dung or of artificial fertilizers give only meagre crops.

He remarks that moderate dressings of lime have served as good a purpose as very heavy dressings.

In these experiments lime or marl were applied in quantities of 2,000, 4,000, 6,000, and 8,000 kilos. to the hectare half a year before the crops were sown, and it was found that while the first effect of liming such land was excellent, the long continued use of lime was decidedly hurtful. During the first year, crops of peas, rye and potatoes were largely increased by the liming, both on recently burned moors and on those which had long been cultivated, but in most cases the after-effects of the lime were harmful, in that the crops gave diminished yields and that the soil seemed to be exhausted. Hence the advice to apply only small doses of lime to such land, and to use clay-marl when possible rather than lime-marl.

Earthworms live in Mellow Humus.

One curious result of the amelioration of peat-bogs in England, by draining and liming, is said to be that the land soon becomes filled with worms, which find abundant support in the decaying vegetable matter, and that a plague of moles is apt to follow in due course; these animals being attracted by the worms on which they feed. It is to be inferred from these observations that, even before the advent of the worms, the limed land must have become fitted to support the useful microscopic organisms which work to bring the soil into a wholesome state of fermentation and to make it fertile enough for supporting large crops.

It needs to be said, however, that while the application of lime to drained bog-land may hasten the coming in of the worms and the moles, these creatures would still appear after a time even if no lime were used in the process of reclamation. I have myself seen them arrive in force on bog-meadows at the Bussey farm, soon after the sour land had been drained and dressed with stable-manure, although no lime was applied. It is probably true, as a general rule, whenever bog-earth is reclaimed and made mellow, that nitrifying (and other) micro-organisms speedily appear in the soil, to be followed in turn by earthworms which feed upon them, and by moles, which prey upon the worms.

The fact may here be recalled that Hilgard has observed on the arid soils of California, that although the presence of carbonate of lime in a soil hastens the oxidation of humus, the proportion of nitrogen in the humus may nevertheless increase, because the carbohydrates in decaying vegetable matters are oxidized more rapidly than the nitrogenous constituents.

Lime promotes Useful Fermentations in the Soil.

It is not improbable that one of the most important uses of lime may be to foster the growth of useful micro-organisms in the soil, perhaps even those which live upon the roots of clover and other leguminous plants. There are experiments by Heiden and Voigt, on the liming of land, which seem to support this view. Indeed, the results obtained by these chemists were so well marked that Heiden was led to declare that "lime deserves to be called a collector or gatherer of nitrogen."

A number of plots of crude, rough, moderately heavy land were tilled and cropped during 10 successive years, and were finally examined as to the amounts of nitrogen contained in them. Plot No. II had received no manure during the 10 years; No. III had been limed 6 times in the course of the 10 years, each time at the rate of 14 short tons to the acre; No. IV had been fertilized with sulphate of ammonia, 7 times during the 10 years; No. V with tri-phosphate of lime, 6 times in the 10 years, and No. VI with sulphate of potash, 6 times in the 10 years. There was found in the soil of the several plots the proportions of ammonia, nitric acid and organic nitrogen that are given in the following table: —

SURFACE SOIL.

Plot.	II.	III.	IV.	V.	VI.
Ammonia	0.0005	0.0021	0.0005	0.0008	0.0010
Nitric acid	0.0048	0.0056	0.0002	0.0017	0.0032
Organic nitrogen . . .	0.0334	0.0588	0.0497	0.0481	0.0493
SUBSOIL.					
Ammonia	0.0005	0.0008	0.0008	0.0003	0.0011
Nitric acid	0.0012	0.0008	0.0022	0.0016	0.0012
Organic nitrogen . . .	0.0459	0.0613	0.0275	0.0353	0.0416

It will be noticed that in Plot No. III (the limed land) there are decidedly larger amounts of organic nitrogen, and even of nitric acid and ammonia than were found in the other plots. It was plain, moreover, that the excess of nitrogen in No. III was not to be attributed to roots that had been left in the soil, for on subjecting the soil to mechanical analysis no considerable quantity of roots could be found in it. Moreover, since the plot which had been fertilized with an ammonium salt (No. IV), had borne larger crops than the other plots throughout the experiment, it is to be inferred that the soil of No. IV must have contained more roots than that of No. III or any of the other plots.

Quicklime may hinder Nitrification.

Many writers have urged that lime, or rather lime-carbonate, does good by promoting the formation of nitrates from nitrogenized organic matter, or from ammonia, within the soil; and recent experiments have shown that, as regards the carbonate at least, this view is correct. From a very early period, indeed, carbonate of lime has been considered to be an essential adjunct to the porous earth of saltpetre plantations, and it has long been known that nitrates are specially apt to form in limestone caves and upon walls plastered with lime. Finally, Warington has shown by experiments that the nitrifying ferments prosper exceedingly in presence of an excess of carbonate of lime, and indeed will hardly do good work without a supply of the carbonate.

It is to be remembered, however, — as has been explained in Volume I, under Nitrification — that quicklime is hurtful to the nitric ferments, and that it might readily happen that one of the first effects of liming a field heavily would be to arrest the nitrification of its humus. Warington found that lime-water is a much stronger alkali than the nitric ferments can bear. Of course, the undue alkalinity of the quicklime will be mitigated as soon as enough carbonic acid to change it to carbonate has been absorbed by it from the ground air, and it must constantly happen in farm practice that the lime is speedily neutralized by the acid humus of the soil, and here of course, lime would finally promote nitrification.

Lime may decompose Minerals.

Another corrosive action of lime is seen in its power to hasten the disintegration of refractory silicates. Such action as this would usually be brought about much more readily by caustic lime than by gypsum, and there can be little doubt that the disintegrating action of lime upon feldspar and other minerals may sometimes be of considerable importance. It has been reported, indeed, that applications of lime have often been found to be specially efficacious on such clay soils as contain many fragments of broken but still undecomposed feldspar; and it is evident that bicarbonate of lime formed in the soil, by the action of carbonic acid on the lime, might react with silicate of potash in the feldspar to form silicate of lime and soluble bicarbonate of potash. Moreover, there are experiments by Fuchs and by Zierl which show that if powdered feldspar is gently ignited with lime, and the mass then digested with water, — or if powdered feldspar previously ignited is boiled with milk of lime for a short time, or digested for a longer period with milk of lime at the ordinary temperature of the air, — much of the potash which the mineral contained will be given up to the water, while lime takes the place of potash in the mineral.

So large an amount of potash may be dissolved in this way that it was proposed, at one time, to employ the process as an economical method of obtaining potash for use in the arts. There are, in fact, many kinds of clays which are acted upon to no inconsiderable extent by lime, even before they have been roasted. If a small quantity of such a clay be stirred into milk of lime, and the mixture be left to itself for a week or two, it will be found, on treating the mass with muriatic acid, that an appreciable quantity of the clay will dissolve, with separation of gelatinous silica, though, as is well known, clay by itself is not much acted upon by muriatic acid. In the case now in question, a part of the lime enters into combination with some of the clay to form a small quantity of a hydrous silicate of alumina and lime, such as has been so often spoken of as useful to hold potash and ammonia in the soil. But during the formation of this compound, there must have been set free from the clay, or loosened up, as it were, within it, whatever of potash or ammonia the decomposed portion of the clay may have contained. It has been shown by Kellner, that lime sometimes acts upon phosphates in the soil to make them more readily available for crops, and that the exhaustive tendency of too frequent applications of lime may depend in part on the using up of the ash-ingredients which the soil contained.

There are experiments by Stoeckhardt which show that caustic lime attacks, not only feldspar, but even powdered quartz and pure precipitated silicic acid, and that it combines with small quantities of silica to form a hydrated silicate of lime which is easily soluble in acids. It is known withal, from the examination of mortar from old buildings, that caustic lime does slowly act upon silicious sand to form small quantities of a hydrated silicate of lime readily soluble in acids. The same easily soluble silicate may be obtained directly by mixing lime-water with recently precipitated silicic acid. It is worth noticing, moreover, that Stoeckhardt's experiments were made upon minerals which had previously been leached with acid and with water until everything soluble had been removed from them.

Scientifically speaking, it would be possible, on the plan of these experiments, to establish compost-heaps consisting solely of lime and clay, with the idea of loosening or "unlocking" some of the useful constituents of the clay. Clay composts have, in fact, been made occasionally in England, from equal bulks of lime and clay, and satisfactory results were obtained; though the motive in these cases was merely to destroy the tenacity of the clay, and this purpose was accomplished in the course of a fortnight.

Hilgard has argued that the presence of lime-carbonate in the soil must often be of great importance for maintaining fertility, because it acts to decompose inert, refractory silicates, and to favor the formation of the more soluble zeolites. He urges that the useful effect produced by the presence of a per cent or two (or more) of lime-carbonate in soils often seems to depend on a kind of unlocking action, i. e. an energizing or rendering active of substances which would remain inactive otherwise. That such action does really occur is made evident by the fact that, in Hilgard's analytical process of digesting soils in an acid, it is found that the so to say limed soils dissolve more completely in the acid than do those which are deficient in lime.

From the "limed soils" acids often dissolve out the alumina so completely that no clay is left behind in the residue insoluble in the acid, and this insoluble residue is smaller anyway in the case of the lime-soils. To this decomposing action of lime Hilgard attributes, in some part, the long-continued fertility of certain cotton-lands in the Southwestern States, which can bear to be cropped for many years because the lime in the soil acts constantly to loosen up potash, phosphoric acid, etc., from their inert compounds.

Another point to be remembered is the fact, which has been illustrated repeatedly by laboratory experiments, that an admixture of lime salts, or even of carbonate of lime, with a soil, increases the power of that soil to absorb and fix potash, soda, ammonia, and the like, from their solutions.

Lime may combine with Silicates.

It may be said further of lime, that it can act by uniting with the hydrous silicates in the soil so as gradually to expel from them potash, ammonia, or magnesia for the use of crops. Heiden has shown by experiments that the fact is as here stated, though in so far as the action of lime-water alone is concerned, a better purpose might perhaps be served by applications of gypsum. It has been argued, however, by some chemists, that the solution of bi- or sesqui-carbonate of lime, which forms naturally and readily in limed soils, may exert no inconsiderable influence to push out potash (and soda) from partially decomposed feldspathic minerals, and from other silicates that contain alkalies, for the lime may combine with the silica of the minerals, while sesqui-carbonate of potash (or soda) goes into solution. (Trommer.)

In view of the various modes of action of lime, as above set forth, it seems possible to understand that both the French and the German writers may be correct in their seemingly conflicting assertions; viz. by the first, that the best action of lime is seen on light, and by the last, on heavy land.

It is certainly true that lime may improve heavy clays by flocculating the finer, colloid portions of the clay, and so making the soil less pasty and sticky than it is naturally; and it is probably true also that lime often does some good on such soils by corroding and disintegrating their constituents. On the other hand, lime may do good on some light, permeable soils, both by cementing their particles to a better capillary condition, somewhat as mortar might, and perhaps by charging the land with hydrous silicates, as has been explained in Chapter VIII of Volume I. The action of lime to correct sourness, or to promote decay, may be more frequently important, perhaps, on heavy lands than on light; while upon light soils the influence of the lime to make the crops healthy, or even finally to promote nitrification, may be of more importance than it is on heavy soils.

It is noticeable, however, that, in so far as the good effects of lime may depend on its power of decomposing organic matters or minerals in the soil, and making their constituents available as plant-food, the same result could usually be obtained more economically by buying and applying small quantities of commercial fertilizers of kinds similar to the substances which the lime has set free.

Lime slowly changes to Carbonate of Lime in the Soil.

It was supposed formerly that, in the field, it could hardly be possible that reactions due to the causticity of lime could occur after the lapse of some little time. Not only are the pores of the soil charged with carbonic acid, which must work constantly to reduce the caustic lime to the condition of carbonate of lime, but a great deal of carbonic acid is produced by the action of the lime upon the organic matters of the soil. Moreover, the lime tends constantly to unite with organic matters in the soil to form humate of lime. But recent investigations by Heiden go to show that a part of the lime may remain in the soil for years in the soluble form, at least on land that has been very heavily limed. Thus, a quantity of earth taken from a plot of land that had been limed at the rate of 14 tons to the acre, early in May, was leached with water half a year later, at the end of November, in comparison with adjacent unlimed land, and there was found 44.5 milligrams of lime in the extract from the limed land, against 4.7 mgs. in that from the soil that had not been limed, i. e. more than 9 times as much lime was dissolved by water from the limed field as from the other. From the subsoil, also, of the limed plot, water dissolved out much more lime than could be leached from the unlimed land, — more than 6 times as much. The figures were 158 and 26 mgs. respectively.

In another experiment, two samples of soil were taken from a field that had been limed some 12 years previously. It was inferred from the large number of fragments of lime that were visible in this earth, that a heap of lime must have stood upon the place whence the earth was taken. There was found in these samples 0.039 % and 0.032 %, respectively, of lime that was soluble in water. Other samples of earth taken from different fields gave results which are stated in the following table: —

No. of years since the liming.	The soil contained per cent of lime soluble in	
	Water.	Hot, strong muriatic acid.
14	0.0197	0.2722
10	0.0235	0.3629
8	0.0232	0.3472

It appears from these figures that the lime soluble in water amounted to a considerable proportion (a fourteenth or fifteenth) of that soluble in the hot concentrated acid.

Heiden argues that the lime soluble in water was chiefly in the form of hydrate of lime, because the soil had an alkaline reaction, and because he found comparatively little carbonic acid in the solution. This last observation is important because, as is well known, bicarbonate of lime shows an alkaline reaction. The lumps of lime also which were found upon the old field did not contain enough carbonic acid to neutralize all the lime that was contained in them. While it is a matter of the deepest interest that the soil of limed fields may be thus highly charged with solutions of lime, it is to be remembered that it is quite within the limits of possibility that the dissolved lime studied by Heiden may have been in the form not of caustic lime, but of some compound of lime and organic matter.

Poor Soils are unfit for Liming.

One conclusion to which the foregoing discussion leads is, that, excepting clays, and some cases where it may do good as a means of correcting sourness, lime is not a thing to be applied to really poor land. Generally speaking, it can hardly be profitable unless the soil is already fairly well charged with the constituents of plant-food. Its function is to alter and improve matters that are already in the soil, and to make them more easily available for crops, as well as to bring the soil into such condition that it can enable added fertilizers to be put to better use than they could have been without the liming. It is an adjunct to be used occasionally, but no proper substitute for manure.

Speaking in general terms, it may be said that lime is used much less freely nowadays than it was formerly, though there are certain localities in Europe where the use of lime has been coincident with the building of railways which have made it possible to procure the material cheaply. On the poor granitic soil of the French province Limousin, for example, great advantages have been gained by applying lime which is brought by rail from the Department of Cher. Thanks to the lime, it has become possible to grow excellent crops of clover, and to keep many animals, and so to obtain adequate supplies of manure. (Dehérain.)

Quantities of Lime applied to Land.

The amount of lime applied to the acre varies widely in different countries, and according to the kind of soil. Heavy clays can bear much more of it than light, sandy loams. Inasmuch as the chief action of lime is undoubtedly to improve the mechanical condition of the land, it is evident that the lime should not be applied in quantities too small to effect this purpose. Ordinarily it should be thought of and applied as an ameliorant in terms of tons, and not as a fertilizer to be used by pounds. In many localities lime is reckoned by bushels each of eighty pounds weight.[1] Thus in

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[1] According to experiments made at the New Jersey Agricultural Station, "A bushel of good stone lime weighs 93 lb.; when slaked it will yield nearly 3 bushels, each of which will weigh about 45 lb. A bushel of unslaked oyster-shell lime weighs 60 lb.; when slaked it will measure more than 2 bushels, each of 40 lb. weight. A bushel of magnesian stone lime weighs 80 lb.; when slaked it measures about 2 bushels, each of 55 lb. weight.

Eastern Pennsylvania, where lime has long been used, the usual dressing is said to be 40 or 50 bushels to the acre, on soils of medium quality, while on deep, rich soils as much as 70 or 80 bushels may be used with advantage. On poor land, it was thought to be best to begin with no more than 20 or 30 bushels, and to increase the dose as the land improved. Formerly, at least when the term of the usual rotation of the locality was 5 or 6 years, every field was limed in its turn, at the time when the grass-fields were broken up preparatory to the sowing of Indian corn. The sod was ploughed under in the autumn, or early in the spring, and the land was harrowed once. Next April, quicklime was deposited in heaps upon the land, and drenched with enough water to make it fall to powder, which was immediately spread while yet fresh, or "warm," as the term is, and harrowed in thoroughly. Occasionally, the lime was applied before sowing wheat in the autumn. Some farmers even interpolated an intermediate dose of lime, applied as a top-dressing to the young grass in November. Stable-manure was not applied at the same time as the lime, but the year afterward, either in the spring for barley, or in the autumn before seeding the land with wheat.

In England 4 tons of lime to the acre are esteemed to be sufficient for light lands, and for land that has been long under cultivation; or, instead of this quantity, more frequent dressings of 1 or 2 tons at a time may be used. In some parts of Scotland, from 60 to 150 bushels of lime are applied at stated periods in the rotation, the usual quantity ranging from 90 to 120 bushels. For old sod-land that has just been ploughed, 6 tons of lime was the dose formerly recommended; and in those days quantities ranging all the way from 6 to 12 tons seem to have been usual applications, the larger amounts being applied in cases where the land had not previously been limed. But it seems to have been recognized very early that the lime obtainable in some localities is much "stronger" than that from others. An English farmer, writing in 1765, has said, "Lime differs in quality as well as land itself. In many countries the crops would be burnt up if 64 bushels were laid on an acre, whereas in Derbyshire there are instances of people laying on 384 and 448 bushels per acre on grass-land."

From 100 to 160 bushels to the acre seem to have been common applications in some parts of England, though it was admitted that different kinds of land require different proportions of lime. Generally speaking, cold clay-soils appear to have been limed more heavily (8 to 10 or 12 tons to the acre), and more frequently also (once in six years, or even oftener) than any others, for the reason that the lime makes such land work more kindly; but the Yorkshire farmer above cited has said, "Whoever tries the experiment of putting as much as 12 tons of lime to the acre on old tilled land, will find himself in an error, especially if the soil be clay, which is apt to be too much bound after the fermentation of the lime is over; but sand lands can never be overdone with lime, provided it be laid on in the spring, and that it is not of that fiery kind which many of the sorts are."

So, too, for improving the cold, raw peat of moors and bogs which have just been drained, as many as 200 or 300 bushels of lime to the acre have sometimes been applied. It is said that these heavy dressings of lime, when combined with judicious ploughings, will, in the course of even a few weeks, bring the peat into a condition fit for supporting crops. There are probably very few localities, however, where the expense of using such large quantities of lime could be justified nowadays by the improvement which it effects.

In 1776, Hunter wrote as follows: "It is generally said that lime answers better upon sand than clay. This observation will undoubtedly hold good as long as the farmer continues to lime his clay lands in a scanty manner. Let him treble the quantity, and he will then be convinced that lime is better for clay than sand. It may be justly answered that the profits will not admit of the expense. I agree. But then it must be understood that it is the application and not the nature of the lime that should be called in question. Clay, well limed, will fall in winter and ferment with acids. Its very nature is changed."

Less Lime is Used Nowadays.

Latterly, smaller dressings at more frequent intervals have become customary in England. More than 5 or 6 tons to the acre are now seldom used there, even on strong land. Instead of applying 4 to 8 tons once in fifteen or nineteen years on land that had been previously limed, the rule is now to apply lime every six or eight years in quantities not larger than 1 or 2 tons to the acre.

In Germany, lime used to be applied at the rate of 6 to 12 tons to the acre once in 7 or 8 years. In France it has always been customary to apply smaller quantities of lime than were formerly usual in England; 3 or 4 tons to the acre once in 7 or 8 years, seems to have been the old rule. Modern French practice, according to Dehérain, goes to show that as little as 2 tons to the acre, applied once in 3 years, is sufficient for light land in regions where the rocks are granites or sandstone, though 4 tons might be applied in case the soil were rich in organic matter. Proof that the dose of lime employed has been sufficient is afforded by changes in the character of the vegetation of the fields, and particularly by the coming in of white clover. On clayey land, 3 tons of lime to the acre may be applied every 4 or 5 years, and on very strong clays — where liming is always useful — the quantity of lime to be applied is to be determined by comparing the cost of it with the profit obtained from its use. In reclaiming peaty land, 2 or 3 tons of lime to the acre may be applied, after the land has been drained, and if profit is got from these quantities, still larger applications may be tried. In Belgium, the rule at one time was to apply some 2.5 tons to the acre once in 10 or 12 years.

Salfeld has found by experiment that on newly-broken sour moor-land (Hochmoor) 900 lb. of lime to the acre is not enough to ensure the successful growing of horse-beans or peas; and Maercker has stated in respect to certain German moor-lands, which suffer from the presence of sulphate of iron, that there would be needed from 4 to 10 tons of lime to the acre merely to destroy this hurtful substance, and to prevent the further formation of it. It is held that deep soils require to be limed more heavily than those which are shallow. Practical men say that the reason why land requires to be limed anew after a longer or shorter interval depends primarily on the fact that the lime tends continually to sink deeper and deeper into the soil. Were it not for this peculiarity, they can see no reason why one good dose of lime should not serve for a century.

According to Schwertz, a practice prevails in some localities of giving the land a mere sprinkling of lime (8 or 10 bushels to the acre), at the moment of sowing grain, i. e. after the land has been prepared for seeding; and it has been suggested that the development of ammonia in the soil by the action of the lime on inert nitrogen compounds may perhaps justify this custom. The ammonia would be set free at the very place where the young plants could have access to it. The lime might serve in some measure also to protect the young plants from insects, and to promote nitrification.

Leaching out of Lime.

It is undoubtedly true that, when lime has been applied to the land in rainy regions, the rain-water which percolates through the soil will carry away much lime, because when either lime or carbonate of lime are present in a soil they unite readily with the carbonic acid which results from the decay of humus or other vegetable matter, and form soluble bicarbonate of lime, which passes down into the subsoil in the percolation water, and in some part goes out of the soil altogether. It has been observed of calcareous soils in England, that carbonate of lime is the most prominent soluble constituent in the water which flows out from field-drains, and that any application of manure which increases the fertility of the land increases also the proportion of carbonate of lime in the drain-water, since the amount of carbonic acid in the soil rises with the amount of crop residue annually undergoing decomposition. With the application of artificial manures there is a large increase of other salts of calcium than the carbonate in the drain-water; thus superphosphate of lime, sulphate of potash and sulphate of ammonia naturally increase the amount of sulphate of lime in the drainage; and when an ammonium salt is applied there is a further production of nitrate of lime through the nitrification of the ammonia. In the experiments of Lawes and Gilbert, the loss of lime which the soil suffers when ammonium salts are applied to it continually has necessitated in some instances the application of heavy dressings of chalk or lime, for in the absence of carbonate of lime the action of the ammonium salts on pasture-grass has been found to be injurious rather than beneficial. (Warington.)

According to Hilgard, there can be no question that the leaching out of lime from soils is one cause of their impoverishment. Because of it, most subsoils in rainy regions contain rather more lime than is contained in the surface soils. The absence of such leaching action in arid regions has been supposed to be one reason why these countries exhibit exceptional fertility when they come to be irrigated. An illustration of the amount of lime which might be removed from a soil by leaching has been given by Schloesing as follows: "There would be no improbability in admitting that the ground air in a fertile or recently-manured calcareous soil might contain as much as 1 % of carbonic acid, or that water lying in contact with that ground air could hold dissolved as much as 0.196 grm. of carbonate of lime to the litre. But in case the rainfall of the locality was 24 inches, and that no more than one-fifth of this water percolated through the soil, that would amount to 480 cubic metres of drainage to the acre, which would carry away 200 lb. of the lime-carbonate.

Carbonate of Lime.

A few words remain to be said about carbonate of lime, as such, though of course wherever caustic lime is applied to land it comes to act as carbonate of lime as soon as it has once been thoroughly neutralized with carbonic acid; and it may well be true that, in many cases, the good effects of liming are really due to the carbonate of lime which results from this neutralization. Indeed, it has sometimes been urged, in respect to certain English localities, that the effects observed during the first year after liming are apt to be inconsiderable as compared with those noticed in the second and succeeding years, and the inference has been drawn that the fertilizing action may really have been due to carbonate of lime rather than to the original quicklime. Limestone gravels have in fact been used in very large quantities in some localities for fertilizing the land, and with marked success in the damp climate of Ireland, as has been set forth by Arthur Young.

Reference has already been made, under Composts, to the fact that the lime-carbonate favors the fermentation of humus and nitrification also. The experiment of Schulze, already cited, is of special interest as bearing upon this point. In repeated instances he charged pairs of glass cylinders standing in mercury, and full of atmospheric air, with equal quantities of loam that was rich in humus of rather sour character. But he mixed the loam of one cylinder with $\frac{1}{10}$ its weight of carbonate of lime, while to the other cylinder he made no addition. After the lapse of from 4 to 8 days he found habitually that all the free oxygen had disappeared from the air of the cylinder that contained the lime-carbonate, and that this oxygen had been converted into carbonic acid by oxidation of the loam, while in the other cylinder not more than half the oxygen was consumed in the given space of time. Ordinarily, the oxidation of the mere loam was more than four times slower than that of the limed loam. This observation consists with practical experience in France, where it has been noticed in dry regions that the organic matter in calcareous soils speedily disappears unless pains are taken to replace it by means of barnyard-manure, or by occasionally growing crops which leave much refuse in the land. On many non-calcareous soils in that country humus tends to accumulate rather than to diminish.

The Humus of Limestone Soils.

In regions of abundant rains, on the contrary, humus of excellent character may accumulate on calcareous soils precisely because the lime-carbonate hastens the partial decay or humification of vegetable matters, such as the remains of plants. It is very noticeable indeed in regions where the soils and waters are calcareous that the humus is, generally speaking, milder, mellower and more fertile than that of non-calcareous regions which are exposed to climates of equal inclemency. It would appear, for that matter, that sour peat or moor-earth is seldom if ever formed in limestone regions in temperate climates. Marshall noticed, long ago, in localities where limestone abounds, that the humus of bog-meadows, and especially that upon the edges of low-lying ditches, where it is exposed to the air, is a rich black mould of esteemed fertility.

It is to be presumed, indeed, that one prime reason of the fertility of many calcareous regions is that their humus is "mild," and subject to rapid nitrification. It is easy to understand how the farmers in such districts might readily come to regard bog-mud as a fertilizer by itself, and that they would be apt to attach but little importance to the making of the composts that are so much esteemed in many granitic countries. The remarkable fertility of Aroostook County, at the extreme northernmost limit of the State of Maine — as contrasted with the comparative sterility of the greater part of New England — appears to depend primarily upon the prevalence of limestones there, and upon their action in favoring the formation of mellow humus.

Hilgard has repeatedly called attention to the fact that the prairie soils of our Western States contain no small proportion of lime, and has insisted — as upon a fact of experience common to all countries excepting those so cold that the formation of moor-earth is specially favored — that wherever a particularly dark-colored upland loam is met with, it may be regarded as good evidence that a calcareous rock or soil will be found lying beneath that loam.

Carbonate of Lime may prevent Puddling.

The importance of the lime-carbonate as a means of hindering the puddling of clayey soils has already been mentioned under the head of Lime. It appears, indeed, that in very many instances it is really a solution of carbonate of lime in carbonic-acid water, i. e. the so-called bicarbonate of lime, which is the effective agent for coagulating the clay. The remarkable clearness of the streams in chalk districts has often been commented upon by English anglers, and the water of the Lake of Geneva offers a noteworthy illustration of the action now in question, for this water is particularly clear in spite of the great turbidity of the glacial streams that flow into the lake. All the suspended matters are coagulated and precipitated as soon as they mix with the lake-water, which is charged with the lime-carbonate. In 10 litres of water taken from the Rhone at Geneva, at a point where it has the same composition as the lake-water, Deville found 789 milligrams of carbonate of lime, 49 of carbonate of magnesia, 466 of sulphate of lime, and 63 of sulphate of magnesia; i. e. in one litre 63.5 mg. of lime and 4.5 mg. of magnesia. Small quantities of alkali salts were present also. As a general rule, any water — whether taken from wells, rivers or ponds — which is noticeably clear, bright and sparkling, will be found to be "hard" from the presence of lime salts.

Other things being equal, there is less risk that a soil which contains considerable quantities of lime-carbonate will be puddled by rain than there would be if none of the carbonate were present. Even when the store of bicarbonate and other saline matters naturally present in the soil-water has been diluted or washed away by rain, new portions of it will speedily be formed to coagulate anew any particles of clay which may have been puddled.

Schloesing has suggested that, if soils could be conceived of that contained neither solutions of the lime-carbonate nor of other saline matters in their pores, it would follow that the earth could no longer have the power to clarify muddy liquids. On the contrary, the soils themselves would be changed to mud whenever rain-water fell upon them, and all brooks and rivers would be muddy, because the clayey and loamy parts of soils would slowly be washed away through them into the sea, until nothing but sand and gravel were left behind. Possibly such elutriation and straining of clay from sand may really have occurred to some extent in geological epochs anterior to the appearance of vegetation on the earth's surface; for when soils contained no humus, and particularly when the waters that washed the soils were warm, it may perhaps have happened that not enough carbonic acid for the rapid solution of lime and the effective coagulation of the clay was brought into contact with the soil.

From the evidence above set forth, it follows, as Holleman has urged, that the ease or difficulty with which any given clay soil can be worked may depend on the amount of lime contained in that soil. Holleman has, in fact, found, in repeated instances in Holland, that when the physical condition of a clay is not improved by applications of gas-lime, the reason of the failure is that this particular clay is naturally calcareous; while in respect to clays poor in lime, he found that their physical condition was almost always improved by applications of this material. As the result of numerous trials, he has concluded that liming will probably improve any stiff clay which contains less than about 0.15 % of lime that can be dissolved out from the soil by means of carbonic-acid water, while clays that contain more than 0.5 % of lime soluble in carbonic-acid water will probably not be improved by liming.

Calcareous Soils are usually Fertile.

Excepting occasional districts where chalk or dolomite predominates unduly — i. e. regions where the calcareous rock is too pure or the climate is too dry — limestone countries are commonly fertile countries. Sometimes they occur as veritable oases in the midst of a sterile granitic region, as in the case, for example, with Aroostook County in New England. It may be admitted, as a general rule, that regions of non-calcareous soils are at a disadvantage as compared with those where the soils are somewhat calcareous.

In some tracts of exceedingly fertile land in Germany it has been found that the soil contains 8 or 9 % of carbonate of lime throughout the entire region; and the good effects of marl and leached ashes all over the world go to show that it is well to have a large store of carbonate of lime in the land. It has been noticed also by geologists that, where limestone formations and deposits of clay meet and mingle, fertile soils are apt to occur. Doubtless many of the fertile calcareous soils now under cultivation were formed originally by the commingling of river-mud and coral-sand in just proportions at the bottom of the sea. Of course, in cases where the organisms which build the coral, or other living things, have been buried in the mud or clay, the final soil may contain a fair proportion of phosphates and other forms of plant-food beside carbonate of lime.

Arthur Young, in dwelling upon the great advantages resulting from the general plenty of limestone and limestone gravel in Ireland, has said: "If as much rain fell upon the clays of England (a soil very rarely met with in Ireland, and never without much stone) as falls upon the rocks of her sister island, those lands could not be cultivated. But the rocks in Ireland are clothed with verdure — those of limestone, with only a thin covering of mould, have the softest and most beautiful turf imaginable."

Chalking of Clay Soils.

It is said to be commonly remarked in England that the clayey and loamy soils of that country are fertile only when they contain an appreciable quantity of lime. Where clay soils occur there on the edge of the chalk districts, it is a common practice to "chalk" the clay. Chalk is carted upon the clay land at the rate of some 80 to 100 cubic yards to the acre, and left to disintegrate over winter, in little heaps 4 or 5 yards apart, which are spread in the spring. "Free chalk — such as is reduced to powder by the frosts — is excellent manure for stiff land, and it produces a complete change in the nature of clays. In some localities in England the land is manured by digging wells in the fields and bringing up the underlying chalk, to be spread about on the land. It is laid out upon the surface, where it is crumbled to powder by the frost, and thus gets incorporated with the loam." (Cobbett.) "By a proper application of this substance, the most tenacious clays are rendered friable and mellow, and their native stubbornness and adhesion overcome." (Banister.)

Some farmers have found chalking a remedy for club-foot in turnips; a disease against which quicklime is ordinarily employed, as has been said. Indeed it is recognized in Europe that turnips grow exceptionally well on calcareous soils, and that this plant is specially grateful for applications of lime or marl. European farmers urge that carbonate of lime, when not in excess, has a favorable influence on the decomposition of farmyard-manure in the soil, and that on this account, as well as for other reasons, it is always desirable that sandy and clayey soils should contain considerable quantities of calcareous matters, as an admixture. But as regards soils composed wholly or in good part of chalk, it is complained — at least in warm countries, such as France — that manure decomposes too rapidly upon them. Indeed, except in rainy countries, chalk soils are objected to on several accounts. They can be easily and cheaply worked, it is true, but they are commonly late and cold in the spring, because of their white color, and are apt to dry out absolutely in midsummer in regions where showers are rare. Frost heaves them badly, and winds blow them away so that the roots of crops may be laid bare. Most of these objections are met in rainy countries by letting chalk soils lie as permanent pastures, which become covered with fine and delicate herbage which is highly esteemed.

The great fact, that limestone regions are fertile regions almost everywhere, does but reinforce the argument, that the character of a soil may often be permanently changed by incorporating with it a per cent or two of lime, either by actually liming the land or by dressing it with chalk or marl or waste-lime of one kind or another. It may even be possible in this way to change rye-land to wheat-land, as Gasparin has urged. When the farmers of New England have come to understand clearly that the leached ashes they so much esteem are really little more than very finely powdered limestone, they will probably begin to use other forms of the lime-carbonate more freely than they do now. There is, by the way, nothing of novelty in this assertion. Ruffin, in his work "On Calcareous Manures," long ago wrote as follows: "Wood-ashes, after being deprived of their potash, have calcareous earth and a small proportion of phosphate of lime as their only fertilizing ingredients; and both together do not commonly make more than there is of calcareous earth in the same bulk of good marl. Except for the proportion of phosphate of lime they contain, drawn ashes are simply artificial marl, more fit for immediate action by being finely divided, but weaker than our best beds of fossil shells."

Attention has already been directed in Volume I to the power of chalk rock and chalky soils to hold water, and a somewhat similar remark will apply to loess formations and to many other fine calcareous soils, notably to calcareous clays which have been left as a residue, where great masses of limestone have been dissolved by water and so carried away. In Maryland, according to M. Whitney, "these limestone soils are too retentive of moisture for early truck. In an average season they would maintain such an abundant supply of water that, although large crops would be assured, the crops would be late in coming to maturity."

Calcareous Sands and Shells.

A sand of carbonate of lime consisting of finely comminuted sea-shells, found in sheltered bays upon rocky coasts, is largely used as a fertilizer upon the coast of Ireland and the Channel coast of France, as well as in some parts of England. From the little ports on the Channel the French farmers transport this sand inland 20 or 30 miles in wagons, and in Cornwall it is carried to even greater distances by rail. It is said to be applied with special advantage to stiff clay soils. According to Dehérain, the best quality of shell-sand is usually applied at the rate of from 70 to 180 bushels to the acre, while samples of medium quality are applied at the rate of from 110 to 230 bushels. In the environs of Cherbourg as much as 300 to 1000 bushels to the acre are sometimes used.

Another account says that it is applied with much benefit to marshy grass-lands at the rate of 10 or 12 tons to the acre. Though often put upon the land directly, it is frequently first made into a compost with peat, pond-mud or stable-manure. According to Gasparin, it is always associated with manure or with seaweeds. The sea-sand is said to improve the character of the herbage in pastures, to destroy moss and innutritious swamp plants, and to favor the growth of leguminous plants. Indeed it has been claimed that the growing of clover and lucern on the granitic soil of Brittany first became practicable through the use of this material. It is esteemed for turnips and for potatoes, and also for the cereal grains.

In Devonshire, England, the shell-sand is applied at the rate of 11 to 13 two-horse loads to the acre before ploughing for wheat; and it is considered to be valuable on grass-land also in that it produces sweet and luxuriant herbage. A Scotch writer has urged that, taking cost into account, shell-sand is the best top-dressing for natural pastures, in his locality, and this is clearly the general opinion on the Channel coast of France. As has been explained already, chalk, like any other form of carbonate of lime, may act, according to the circumstances, either to loosen stiff clays or to bind some soils which are naturally too loose or incoherent.

Shell-lime versus Shell-flour.

Oyster-shell flour, such as was made in great quantities in Boston a few years ago, was as good, and probably better, than the shell-sand. But there is small reason to believe that the powdered shells are any better than lime obtained from shells that have been burnt. In experiments made upon light land at the Bussey Institution, it appeared that oyster-shell flour, that is to say fresh oyster-shells ground extremely fine, did not give quite so good crops as caustic lime that had been prepared by burning oyster-shells. Moreover, on analyzing sea-shells, it appears that the organic matter which they contain is wellnigh free from nitrogen. There is no evidence that this organic matter is of the least use as a manure, unless indeed it may perchance be fit food for microscopic ferments. Hence there is no reason why the farmer should be at the expense, either of having the shells ground, or of carting the useless constituents which can be expelled by burning.

The cheapest way to obtain carbonate of lime in powder is to burn the original limestone, or sea-shells if they are to be had, and to slake the product with water. The slaking may be done in heaps covered with moistened earth, as has been described, and the fine powdery hydrate of lime spread directly upon the land, or the lime may be used in the compost-heap; or the quicklime might be left to become air-slaked by exposure to the air, and the product be applied to the land instead of leached ashes. Air-slaked lime is sometimes spoken of as a hydrocarbonate of lime. It is in fact a particularly intimate mixture of the hydrate and the carbonate.

Of course it must happen, whenever freshly slaked lime is applied directly to the land, that it will act at first as caustic lime. Only after that action is finished will the influence of carbonate of lime be much felt. But manifestly by proceeding in this way the affair is complicated by the caustic lime which acts upon the land at one stage of the process, and no one can say just what carbonate of lime might have done if used by itself. It is not impossible that cases may occur where the action of the caustic lime upon the soil would be detrimental; and it is to be noted that, in such event, the difficulty would only be partially overcome by allowing the quicklime to slake in the air.

There is always one great advantage to be credited to quicklime, in that the cost of transporting it will be decidedly less than that of transporting powdered limestone. The atomic weights of calcium, carbon, and oxygen are respectively 40, 12, and 16; and the molecular weight of carbonate of lime ($CaCO_3$) is 100. But there are 44 lb. of carbonic acid (CO_2) in that amount of pure carbonate of lime, that is to say, almost one half the weight of the material; and by expelling this carbonic acid at the quarry, there will be just thus much less of dead weight to be transported to the farm.

The argument as previously stated means merely, that by applying powdered limestone or sea-shells the experimenter is in so far master of his position. He will know precisely what he is doing, and be able to judge from the crop whether or not the lime-carbonate has done any good. But when the carbonate has been obtained as a secondary product by starting with quicklime, it can never be known with certainty whether the observed effects should be attributed to caustic lime or to the carbonate.

Use of Leached Ashes.

It is not impossible, when the modes of action of lime compounds come to be understood more clearly than they are now, that only carbonate of lime will be applied to some kinds of soils, and the use of quicklime be restricted to special varieties of land and to the compost-heap. This conclusion is foreshadowed by the extended use that is made even now of leached ashes in many districts, as well as by French experience with shell-sand as just now described. Indeed, in direct, comparative trials of lime and shell-sand, Philippar obtained per hectare 4,570 kilos. more parsnips, and 3,200 kilos. more potatoes, and in the case of rye 870 kilos. more grain and 2,950 kilos. more straw, than were got from the limed land.

In some parts of Rhode Island, Connecticut, Vermont, and Massachusetts, leached ashes have long been highly esteemed, and they continue to be used in these localities very freely, even when the cost of the material is high. As much as 18 or 20 cents the bushel of 55 lb. is said to be paid for Canadian leached ashes in Connecticut. Leached ashes are always more or less moist, and may be estimated to contain 35 % of water on the average, as received by consumers hereabouts. Nearly half of the moist material is carbonate of lime in the condition of a fine, soft powder. There are 3 or 4 % of magnesia also, beside clay, sand, charcoal, and other impurities. Such ashes rarely contain as much as 1 % of potash, or more than a per cent and a third of phosphoric acid. If the carbonic acid be classed as inert matter, together with the sand and charcoal, it will appear that scarcely more than one-third the weight of leached ashes can be regarded as possessing any fertilizing value whatsoever.

Factitious Leached Ashes.

S. W. Johnson has suggested that leached ashes might readily be imitated by mixing together 30 lb. of fresh-burned shell-lime,[1] 8 lb. of kainit, and 10 lb. of fine bone-meal. These materials would supply 28 lb. of lime, 2.8 of phosphoric acid, 1.0 of potash, and 0.7 of magnesia; and, with the exception of magnesia, which is rarely lacking in soils, would probably be equal to 100 lb. of leached ashes, as used for fertilizing purposes. He urges that, in many localities, such a mixture might be economically substituted for leached ashes; and that, still better, such of its components as experience might show to be useful could be used to greater advantage than leached ashes themselves.

It is to be presumed that the soils on which leached ashes do their best service are specially fit for nitrification, and that this process is promoted by the lime-carbonate. In this view of the matter, leached ashes would be of little use on soils not rich enough in organic remains to admit of ready nitrification, unless indeed they were used in conjunction with farmyard-manure, or some other source of nitrogen. This idea consists perfectly with the field observations of Schulz, that the fertilizing action of farmyard-manure may be decidedly increased by applying finely powdered carbonate of lime and ploughing it under with a shallow furrow. So too, Maercker, on applying similar dressings of carbonate of lime, as an addition to dressings of sulphate of ammonia, got better results than were obtained by means of the sulphate without the lime-carbonate.

Beside the direct action of carbonate of lime in feeding the plant and reacting upon the various matters which occur with it in the soil-water, it has a distinct though feeble power of decomposing organic matters, something as an alkali would. There is nothing very extraordinary in this, for, as is well known, the solution of carbonate of lime in carbonic-acid water has a decided alkaline reaction; and, as the experiments of Johnson have shown, the action of carbonate of lime on peat is real though feeble.

Carbonate of Lime a Regulator.

The presence of a quantity of carbonate of lime in a soil may sometimes be useful as a safeguard against, or as an addition to, saline fertilizers. Thus, when chloride of potassium, sulphate of potash, or common salt are applied to land that contains carbonate of lime, the salts are slowly decomposed, with formation of bi-carbonate of potash, or bi-carbonate of soda, as the case may be, and these alkaline compounds have usually a better fertilizing action than the chlorides and sulphates whence they came. In this case the carbonate of lime acts as a regulator, as it were, to keep the land at its best; and so it is with regard to nitrification, as has been said. According to Hilgard, who bases his remark on observations and analyses of the virgin soils of our Southern and Western States, phosphates are more readily assimilable by crops growing on soils which contain an adequate supply of lime than by those growing on non-calcareous soils. He finds that sandy loams containing no more than 0.1 % of phosphoric acid will yield fair crops during a term of 8 to 15 years, provided the soil contains lime enough, while twice this proportion of phosphoric acid will not serve any better purpose than that when there is a deficiency of lime. For that matter, there is abundant evidence — as has already been set forth under Lime — that carbonate of lime often acts as an efficient agent for decomposing silicates in the soil and liberating the plant-food which is contained in them.

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[1] Perhaps it would be well to slake the lime, and then expose it to the air in a barn cellar, with occasional stirrings, before adding the other ingredients.

Marls.

In connection with lime compounds marls should be considered. The word "marl" is a somewhat vague term, applied to mixtures of calcareous earth and various proportions of clay, or loam, or sand. There are marls containing no more than 5 % of carbonate of lime, and others that carry 50 or 80 % of the carbonate.

Shell marls, so called, consist of deposits of clay and silt, admixed with small shells, that are found beneath the surface soil of swamps, and sometimes at the bottoms of ponds. They must not be confounded with the diatomaceous earth (sometimes of pure white color), which is often found in similar situations, and which consists of innumerable silicious shells of microscopic organisms. Occasionally, shell marls contain very large proportions of carbonate of lime. The heaps of oyster-shells, or of shells of sea or fresh-water clams, found in many places near the sea or on the borders of ponds and rivers where Indians formerly congregated, are in no sense to be regarded as marl. For the farmer, these shell-heaps are simply stores of limestone fit to be burned to lime when the conditions are favorable for this enterprise.

Generally speaking, it is only the carbonate of lime in a marl that gives it its fertilizing power, though there are some rare varieties which contain appreciable quantities, not only of phosphoric acid and potash, but of organic matters rich in nitrogen. The lime-carbonate acts, of course, to correct acidity and to promote the decay of organic matter; and, as has been said already, after it has been dissolved by the carbonic-acid water in the soil, it serves to flocculate colloid clay, and to favor nitrification. The good repute in which marls are held depends upon the fact that they are often found far inland in the hearts of agricultural regions, and may be readily applied to the neighboring land at no great cost for transportation. Unlike quicklime, they can rarely do any harm, for there is nothing caustic or hurtful in them. Moreover, they are often applied in such large quantities as to alter the texture of the soil, and to serve as true "amendments."

Upon light or sandy soils in particular, such as are apt to become too loose when worked, great benefit is often derived from methods of tillage which tend to make the land compact. The use of the roller, folding with sheep, teathing with cattle, and methods of shallow ploughing have all been employed to this end, and so has marling. It was customary at one time in certain districts of England to occasionally cover the light lands with heavy dressings of a marl which has been described as being usually a strong clay containing a great deal of lime. It is evident enough for that matter that a light soil dressed with seventy or eighty thousand pounds of clayey or loamy marl to the acre will be made sensibly heavier, and so, conversely, of a sandy marl applied to clay.

Upon some of the low-lying fen-lands of Lincolnshire, great improvements have been made by applying clayey marls both to peats and to peaty sands. The benefit of a thorough dressing with marl is said to be felt during ten or twelve years, though the effect is very variable, according to the character of the marl and of the soil. It is to be noticed, however, that in some of these instances mere clay, devoid of calcareous matter, might perhaps have answered nearly as good a purpose as the marl. Indeed instances are not lacking in European experience where clays applied in this way have served excellently, especially as a means of bringing in white clover upon poor light calcareous land.

As a general rule, however, it is the fact of admixture of clayey and calcareous matters which makes marls so serviceable "both to stiff and to thin soils, breaking the one and giving substance to the other." "It mends any kind of land," says a writer on husbandry, early in the 16th century (as cited by Thorold Rogers). Gasparin cites examples where good results were obtained habitually in France by applying 11 tons to the acre of a marl which contained 77 % of pulverulent carbonate of lime, or 12 tons of a marl containing 68 %; and Dehérain says that it is still usual in that country, in regions where marl is employed, to apply it at the rate of from 10 to 20 tons to the acre once in 15 or 20 years. In the 17th century, in Lancashire, England, it was customary to apply marl every 12th year to land that was kept constantly under the plough. (Houghton.) The old French writer Puvis argued from a theoretical point of view that in marling land as much marl should be applied as would be sufficient to add to every 100 lb. of soil moved by the ploughshare, 3 lb. of carbonate of lime. This idea was based on estimates of the amount of calcareous matter naturally contained in some rich clays and on practical experience of marling, though as Gasparin has pointed out, marl has been known to produce excellent effects when, instead of the 3 % insisted upon by Puvis, it added to the land less than 0.8 % of carbonate of lime.

It needs to be borne in mind that the mechanical condition of a marl has much to do with its value. Just as coarsely crushed bones are worth far less to the farmer than bone-meal, so a rough, lumpy marl will have less value, other things being equal, than one whose particles are fine. It follows, of course, that mere chemical analysis of a marl is not sufficient to determine its value.

Marls are commonly classed, according to their mechanical condition or consistence, as stone marl, shell marl, earthy marl, or slaty marl. A striking peculiarity of the really good marls is their capacity of falling to powder under the influence of the weather after they have been spread upon a field. This phenomenon depends upon the unlike behavior towards water of the clay, the sand, and the calcareous earth which the marl contains. The clay swells on being wetted by rain, while the sand and the lime-carbonate do not. When dry weather sets in, the moist clay shrinks in upon itself, while the sand and the lime compound remain unchanged. Hence, by alternate wettings and dryings, the coherence of the marl is destroyed, and the original lumps of it gradually crumble to powder. In winter also the crumbling process is hastened, when the weather occasions alternate freezing and thawing.

The use of old mortar, or plastering taken from buildings that have been burned or otherwise demolished, though hardly analogous to marling properly so called, may in general be regarded merely as an application of coarse carbonate of lime, though there is often some gypsum in the mixture, more or less caustic lime, and occasionally a little nitrate of lime, especially in plastering, which is to be accounted a better fertilizer than mortar because it contains cow's hair, as well as lime and sand. Other kinds of refuse lime which are to be had, in some localities almost for the asking, are the "scum" from sugar-houses and the "scutch" of skin-dressers, already described in Volume I, and the waste lime of soap-boilers, which consists chiefly of carbonate of lime.

Recapitulation.

To recapitulate, and the question now is of lime proper: —

Lime may act to alter the capillary condition of the soil, both by coating the earth, as was explained, and by flocculating the colloid clay in it.

It may act on hydrous silicates in the soil to push out from them potash, or the like.

It may decompose the inert nitrogen compounds in vegetable mould, and may even do good by merely disorganizing vegetable remains.

It may neutralize undue acidity, whether caused by an excess of humic acids, or by the presence of ferrous sulphate.

It may destroy insects and worms, and some hurtful fungi: though the presence of carbonate of lime in the soil is important for nitrification.

It may help to disintegrate rocks and minerals.

The presence of it in the soil often increases the "absorptive power" of the soil; that is to say, the power of fixing and holding potash, etc.

CHAPTER XXVII.

SODIUM COMPOUNDS.

Of sodium compounds, considered as fertilizing agents, comparatively little need be said. Methodical experiments have shown that sodium is apparently not essential to the life of agricultural plants. Crops can grow perfectly well without it. Or, at the most, they need so small a trace of soda that enough can always be obtained from the supplies to be found in the soil, or even in the air. The soda usually found in the ashes of plants is accidental and non-essential. The old notion that soda could replace potash in the plant has been disproved.

Animals, to be sure, need salt, or some other sodium compound, in order that they may live; and, ordinarily, they obtain the chief part of their supply of soda from plants. But these considerations have little or no bearing on the question of agriculture. Domestic animals might always be supplied with soda by administering to them salt, or sulphate of soda, directly; and it would be economically absurd to send them the soda by the roundabout way of the plant. And yet, in spite of all this, common salt is often found to do good service as a manure.

Mode of Action of Common Salt.

The explanation of this fact seems to be that the salt acts indirectly. It effects the decomposition of substances already present in the soil, and sets free from them some things which are needed by plants. It is somewhat with salt as it is with gypsum, except that, while gypsum pushes out potash with especial ease, as well as magnesia and ammonia, from the hydrous double silicates, common salt displaces lime first of all, then magnesia, and potash (as well as some phosphoric acid) only to a subordinate extent. The discovery, however, even of thus much, viz. that salt acts indirectly to dissolve matters that are already in the soil, has helped to clear up one of the most obscure points in the chemistry of agriculture.

Until a comparatively recent period, it was impossible to comprehend the conflicting statements about the use of common salt that were published every day. One farmer found it a valuable manure; another was led to regard it as a poison sure to destroy his crops, while a large number of observers, perhaps the majority, could not perceive that they derived either benefit or damage from its use. On the whole, the verdict of most practical men appears to have been rather unfriendly to the use of salt. A good example of the experiences which have led to this conclusion is seen in an experiment made by Lawes. Two contiguous plots of moderately good land, devoted to the continued growth of wheat, were dressed every year for 20 years with a mixture of mineral fertilizers and ammonium salts; but during one term of 3 consecutive years one of these plots received 3 cwt. of common salt, in addition to the regular fertilizers, while the other plot got no salt. Some of the results of this trial are given in the following table. The harvests are the averages per year and per acre for the terms of years stated: —

Terms of Years.	Bushels of Wheat.		Total Crop, lb. Grain and Straw.	
	Salt Plot.	No Salt Plot.	Salt Plot.	No Salt Plot.
3 years before using salt . . .	32.25	32.75	5,988	5,976
3 years with salt	30.00	30.25	6,535	6,568
10 years after using salt	40.75	40.75	7,799	7,811
The 16 years	37.25	37.25	7,222	7,234

It is now known, however, that, with many soils, lime, magnesia and potash can be given to the crop by applying common salt, or any other soluble sodium compound, to the land. That is to say, the salt acts to loosen up or to set free the potash of the soil, much in the same way that gypsum does. Berthier observed, long ago, that lucern-plants, grown on a highly saline soil, contained an abundance of potash and hardly any soda. Wolff, in his turn, grew buckwheat on an experimental field, one-half of which was dressed heavily with common salt, while the other half was left unmanured. On analyzing the ashes of the buckwheat straw, he found that the portion of the crop which had received the salt contained less soda, but more potash, than the other.

An application of common salt to the land might thus exert a decided fertilizing action, by merely pushing out lime and potash from the surface soil, and sending them down to where the roots of the crop are growing. The probabilities are, however, that this elimination of potash can usually be effected more cheaply by means of lime compounds than by means of sodium salts; and if a sodium salt were used for this purpose, the nitrate, which is a valuable manure of itself, because of the nitrogen contained in it, might be preferable.

Voelcker was inclined to attach considerable practical importance to the fact observed by him, that salt has power to liberate ammonium salts from the feeble combinations in which they exist in soils which have been highly manured with rotten dung, with guano or with ammoniacal fertilizers. It is well known, he says, that salt is most beneficially applied, either alone or in conjunction with guano, to light land after a good dressing of farmyard-manure. On land in good heart, and well-manured, salt alone often produces a large increase of wheat or other grain, perhaps through the liberation of ammonia and the rendering of it immediately available for the use of the cereal crop. On land out of condition, salt would not produce this favorable effect.

Nowadays it would usually be better policy to apply a potash compound directly rather than to count upon the indirect action of salt or of any other sodium compound. For example, Voelcker, on applying muriate of potash to land seeded with clover and Italian ray-grass, obtained a vigorous growth of clover, and a strong growth of ray-grass also, with the result that there was a material gain of hay as compared with land that had received no manure; while common salt applied to an adjacent plot had no effect upon the product.

Several chemists have studied the disintegrating or solvent action of common salt, and of a variety of other saline substances, upon soils, and rocks, and minerals, not to speak of multifarious experiments of analogous character relating to fixing power. Some of the most noteworthy of these trials are those of Dietrich (Hoffmann's Jahresbericht, I, 29 and V, 12) and of Beyer (ibid., XIII, 22).

Use of Salt to check rank Growth.

Salt is sometimes used to check vegetation. That is to say, it is employed not infrequently in England to hinder the growth of grain-crops, or rather to prevent the stalks from becoming too rank on rich soils, or on soils too highly charged with nitrogenous manures. It is a matter of familiar observation in Southern France, that wheat grown on certain saline soils near the mouth of the Rhone, has a short, firm straw, and is much less liable to lodge than that grown on non-saline land. It has been found practicable to materially increase the yield of wheat on the saline land by manuring heavily. (Gasparin.)

Methodical experiments by Hannam, on oats and barley, have shown that dressings of common salt tend to increase the quantity of grain in a greater ratio than the straw, to improve the quality of the grain, to render the straw white and brittle, and to promote its ripening. In respect to wheat, also, salt was found to have a slight tendency to increase the produce of grain and to decrease the weight of the straw, although it did not diminish its bulk. The weight per bushel of the grain was increased. Some farmers have claimed that wheat grown on land dressed with salt will ripen on an average a week sooner than wheat in the manure of which salt had formed no part.

It was a not uncommon practice formerly to mix the true Peruvian guano with salt, and to mix soot with salt, and the English farmers still use salt to hinder their grain-crops from running to straw in wet seasons. As would naturally be expected, salt does not act in this way on all kinds of land, though on some strong soils it is known to materially strengthen the wheat-plant. The use of it for this purpose would clearly be inadvisable on land not rich enough to cause rank growth. Voelcker, who found salt to be a useful addition to nitrate of soda employed for top-dressing wheat, says: "Salt applied in any quantity to cereal crops and to grass-land certainly does not increase the produce. By checking over-luxuriance, it to a certain extent prevents the growth of rank grasses, and produces a finer herbage; and, in the case of cereal crops, it keeps the straw shorter and thereby prevents their getting laid at harvest-time. . . . When strewn upon the grass of permanent pastures, salt sometimes has a decidedly injurious effect. In one instance, where salt was applied at the rate of 5 cwt. to the acre, the yield of grass to the acre was 760 lb. less than from contiguous unsalted land. Fertilizing materials which are very soluble in water, and are not absorbed chemically and rendered insoluble by the soil, require to be used sparingly, and should always be applied in showery weather, in order that they may be washed into a large body of the land."

In the words of an English writer: "Common salt is used principally for wheat upon the lighter loams and sands, at the rate of 2 to 4 cwt. to the acre. Its general effect is to stiffen the straw without increasing its bulk, and to assist in the perfect filling of the ear." Upon the farm of Mr. Ellis, near Guildford (England), the soil of which consists chiefly of a deep, rich loam that has long been carefully cultivated, salt was at one time habitually used upon winter wheat, particularly that which was sown after clover or grass, and usually with beneficial results. It was customary to apply the salt in autumn, either before plowing under the sod, or at the least before sowing the grain; and it was believed that, on soils similar to that of this farm, salt checks the ravages of slugs and worms, though it may be less useful on heavy clays.

In order to exhibit the merit of salt, an experiment was tried by Mr. Ellis as follows. Quarter-acre plots were marked out upon a field of wheat, the soil of which was a sandy loam upon a gravelly subsoil. Eight loads of dung to the acre had been applied to the clover and bent grass that preceded the wheat, and 2 cwt. of coarse salt were trewn in March upon one of the experimental plots. There was harvested from the quarter-acre that received —

The Salt.	lb.	No Salt.	lb.
9 bushels of headwheat, weighing 61 lb. to the bushel	549	8 bushels of headwheat, weighing 61.75 lb. to the bushel	494
1 bushel and 5 gallons tailings	90	1 bushel tailings	54
	639		548

That is to say, there was gained by the use of salt 91 lb. of wheat, or at the rate of 6.5 bushels to the acre. The straw from the salted plot weighed 786 lb., and that from the unsalted plot 696 lb., i. e. there was a gain of 90 lb. straw, or 360 lb. to the acre. On this farm, no great success had been got from the use of nitrate of soda upon wheat, but a mixture of 1.5 cwt. of Peruvian guano and 2 cwt. of salt, sown as a top-dressing in the spring, had served extremely well "when the land was not in sufficiently good condition to bring on the wheat-plants satisfactorily."

So too the tendency of nitrate of soda to encourage mildew upon wheat, in England, and to make the crop lodge, may be counteracted by using a moderate quantity of sea-salt in conjunction with the nitrate. In practice a mixture of one cwt. of sea-salt, and one cwt. of nitrate of soda to the acre of land, applied as a top-dressing to wheat in the spring, has been found to be useful. It is said to be best not to sow the whole of the mixture at once, but to apply it in two doses at a fortnight's interval in showery weather. In illustration of this matter, Pusey has reported the following harvests: —

White Wheat.	Bushels to the Acre.	Red Wheat.	Bushels to the Acre.
Undressed	21	Undressed	19⅜
2 cwt. guano	24	———	—
Nitrate and salt	25½	Nitrate and salt	27⅛

Pusey suggests that the mixture may do good service on cold undrained clays, and particularly for curing defects in a crop arising from season or from poverty of soil, as when wheat has been injured by frosts in late winter or by the wire-worm.

Doses no larger than 42 lb. of the nitrate and 84 lb. of salt to the acre, have been found to restore early sown barley that had suffered severely from frost. The action of the fertilizer was immediate; the grain-plants soon recovered their color and grew half a foot higher than a half-acre strip to which none of the mixture was applied. The fertilized part of the field yielded at the rate of 47 bushels to the acre and the other part 40 bushels.

Physiological Action of Salt.

The physiological action of salt in these cases is not well understood; though from the effects produced by salt upon potatoes, beets, hemp and flax, as will be stated directly, it is evident enough that it may exert no small influence upon the life of plants. It is not impossible that salt may sometimes kill the nitrifying ferments or some other organisms, that work to make the soil nitrogen active, or, at the least, hinder their development. Possibly the effect of the salt may be due to a general weakening of the plant. As everybody knows, large doses of salt will kill most plants. Perhaps smaller doses may check growth by giving the plants an illness from which they slowly recover. There can be no question as to the practical fact that salt does retard the growth of plants when applied to the land in quantities above 3 cwt. to the acre. Voelcker was led to believe that to this fact must be attributed the great utility of salt upon mangolds grown on light and sandy soils.

On the lighter kinds of soils, he says, and especially when the season happens to be dry, roots are apt to pass so rapidly through all the stages of growth that their leaves begin to drop before the plants have had time either to collect food from the atmosphere or to accumulate mineral matters from the soil in sufficient quantity for the development of an abundant crop of bulbs. Farmers often notice, when dry weather sets in, that root crops are liable to dwindle away and to yield hardly half a crop. But by applying salt in moderate quantities to land otherwise well-manured the life of the plant is prolonged and a larger crop of bulbs is obtained. On such soils, the application of 3 or 4 cwt. of salt to the acre gave Voelcker a large increase of roots, and quantities as large as 7, 8 and even 9 cwt., so far from doing any harm, increased the produce of mangolds by 2.5 to 4 tons to the acre. Indeed, in some of these experiments with mangolds, common salt gave as good results as those obtained by using kainit. He urges that the salt hinders the plants from ripening off too quickly and keeps them not only vegetating but in good growing condition. In the Eastern counties of England, the moderate use of salt has materially increased the root-crop, apparently by virtue of this retardation of the growth of the plants.

On the light chalky soils of Norfolk County, England, where high farming is skilfully practised, considerable quantities of salt have been used. It is said to have been applied to mangolds, generally in conjunction with guano, at the rate of from 3 to 5 cwt. to the acre, being sown upon the farmyard-manure. It was found to very much increase both the weight and the quality of the beets, and on light soils, in seasons of drought, it retained moisture in the land. Salt was used there extensively also with all sorts of top-dressings, as it tends to strengthen straw and brighten the appearance of grain.

Much must depend, of course, on the character of the soil; thus, Caird in experiments on the growth of mangolds near London, on good gravelly loam, found 5 cwt. of salt to the acre to be a useful addition to guano and dung. He harvested tons and cwt. of beets as follows from one acre of land when dressed with

	Tons.	Cwt.
12 cwt, of superphosphate alone	14	19
7½ cwt. of Peruvian guano	17	17
40 cubic yards of dung	21	3
20 cubic yards of dung and 4 cwt. guano	23	16
20 cubic yards dung, 4 cwt. guano and 5 cwt. salt	30	12

But on stiff clay soils the use of salt upon mangolds is injurious, because the ripening of the crop would usually be too much retarded. Voelcker holds that more than 5 cwt. of salt to the acre applied to stiff, wet, clay soils, or to such soils as are cold and which only slowly bring grain, roots and grass to maturity, would be an excessive dose and would do mischief, " for salt has a remarkable tendency to prolong the period of vegetation and to delay the arrival of maturity. Consequently, when it is misapplied the crude juices circulating in the unripe leaves are not sufficiently elaborated or ripened for the production of a large and heavy crop, within the period during which roots can be left in the field. One reason why superphosphates are excellent for roots on stiff clays is that they promote early maturity." Further remarks by Voelcker on the use of salt for mangolds will be given on a subsequent page.

Lawes has reported an experiment with mangolds, on tolerably strong land, where — in addition to other fertilizers, which were the same for all the plots — one acre of land received 5 cwt. of salt and another acre 10 cwt., while a third acre was left without any salt. He says, "One thing which struck me immediately was that the plants which had no salt grew faster than those which had it. There could be no mistake about the matter. The salt evidently appeared to check the growth of the mangolds. This went on for several months, and at one time there was a great difference between one set of roots and the others; but at the time of harvest the yield of roots from the no-salt acre was 21 tons, 2 cwt., that from the acre with 5 cwt. of salt was 20 tons and 10 cwt., and where 15 cwt. of salt were applied there were only 18 tons of roots. As regards tops, the yields were 7 tons, 6 cwt.; 8 tons, 5 cwt., and 7 tons, 8 cwt. respectively.

It may here be said that, although excellent in many cases for mangolds, salt acts injuriously on beets which are grown for the use of sugar makers, both by retarding the ripening process and by debasing the juice, i. e. by preventing a considerable portion of the sugar in the beet-juice from crystallizing. So also in experiments where salt was applied to wheat on a good clay loam, Lawes noticed that the bushel of grain was not heavier when salt was used, that there was practically no difference in the proportions of grain and straw, and that the proportion of offal corn was a little larger when salt was used. But it is evident that these negative results, obtained on land that was in good condition for ripening wheat, do not invalidate the dissimilar experience of other farmers operating on highly manured land and on soils of different character.

Wheat can bear much Salt.

The English engineer Parkes has called attention to the capacity of wheat for supporting large quantities of salt, in the following terms: " The quantity of salt in which the wheat-plant will flourish is curiously illustrated on the warped soils of the river Humber, and would scarcely be credited unless seen. Thus, the whole of a large reclaimed piece of warped land was planted with wheat for the first time in the autumn of 1844. When I saw it, in the autumn of 1845, the surface of the ground was crystallized all over with salt, evidencing the enormous quantity which the mass of the bed must have contained; yet from this first crop, as I was told, 24 bushels of grain to the acre had been threshed out. The order of culture there after warping is to leave the land to the occupancy of what is called sheep-grass, which naturally skins it for three years and then begins to die off. The land is then plowed and sown with rape which is allowed to go to seed. The rape-plant is considered to remove the very injurious excess of salt, and great crops of it are obtained. Wheat follows the rape, and after the wheat any other crop may be grown for many years to the farmer's liking and without the aid of manure."

Possibly it is the chlorine in the salt which acts to restrain the growth of wheat, rather than the sodium. If this be so, it might be better to use chloride of potassium (Stassfurt muriate) rather than common salt; or possibly a light dressing of chloride of magnesium, which would be cheaper even than salt, might serve the purpose. It would be interesting to study the comparative action of common salt and of chloride of potassium upon some of the over-rich bottom-lands at the West. On the so-called American Bottom in Illinois, for example, the growth of stalks and straw is said to be enormous in proportion to the yield of grain. Cornstalks grow ten or twelve feet high, and are sometimes five inches in circumference, while at about the height of a man's head they bear a single ear of corn. For all the rank growth of stalks, the harvest is hardly 50 bushels of Indian corn, or 25 bushels of wheat, to the acre. It would be an interesting experiment to try whether salt, or any other chlorine compound, would in this case bring the stalk production into fit relations with a proper crop of grain.

Salt Toughens Flax and Hemp.

It is not in the least unlikely that salt may exert other physiological effects than those just now suggested, for Nessler has noticed that tobacco grown on land manured with salt had tougher and more flexible leaves than that grown on adjacent unmanured land. So, too, hemp that had been lightly manured with salt yielded a larger amount of useful fibre, and a fibre of superior quality, than was got either from unmanured land or from land fertilized with sulphate of ammonia. Flax also, in Fleischmann's experiments, gave a third more seeds, a quarter more straw, and

100 % more long flax-fibre, when manured with salt than when no salt was applied to the land; and Mayer calls attention to the fact that, on the newly-embanked polders of Holland, flax succeeds well, even when the land is still somewhat saline, and wholly unfit for growing merchantable tobacco. It should be said, both as regards flax and hemp, that the suggestion was thrown out many years ago that a stronger fibre is obtained from fields that have been lightly manured with common salt. (Gasparin.)

It has often been noticed, moreover, that dressings of salt, and even of chloride of potassium, tend to make potatoes waxy rather than mealy. Stoeckhardt has in fact shown, by an elaborate comparison of numerous experiments, in which the action of salt could be contrasted with that of other fertilizers, or with that of unmanured land, that, as a general rule, the percentage of starch in potatoes is diminished when the land has been dressed with chloride of sodium, either by itself or as an addition to other fertilizers. Even the yield of tubers is apt to be diminished by the presence of salt in the soil. Stoeckhardt urged that it is a physiological fact that, when common salt is brought into contact with the roots of the potato-plant, the growth of the latter is checked, and its power to form organic matter and to store up starch in the tubers is hindered to a remarkable extent.

When applied to sugar-beets also, common salt — as well as chloride of ammonium and chloride of potassium — tends to diminish the yield of sugar, and of dry organic matter, while the proportion of nitrogenous substances and of ashes is increased. In an instance where the yield of grass had been largely increased upon a meadow by salting it, Hellriegel found that the proportion of nitrogenous matter, ashes and cellulose, in the crop, had been increased by the use of the salt, while the proportion of carbohydrates was diminished. Indeed, Loew admits, as a general rule, that, in crops fed with alkaline chlorides, cellulose is increased at the expense of starch.

Voelcker found in his experiments that common salt applied to potatoes in any considerable quantity rather injures than benefits the crop, especially in dry seasons, and that it has a more decidedly prejudicial effect on clayey loams than on lighter, sandier soils. Although small quantities of salt sometimes increase the potato-crop on light land, especially when the salt is used in conjunction with a superphosphate, he deems it hazardous to apply as much as

4 cwt. of salt to potatoes on light loam in a dry season. In one experiment, where 4 cwt. of plain superphosphate and 4 cwt. of kainit per acre were applied to sandy loam, in a dry year, 8.5 long tons of potatoes were obtained, while a contiguous plot, manured with 4 cwt. of the superphosphate and 4 cwt. of common salt, gave less than 4.5 tons tubers, i. e. a crop no better than that yielded by the unmanured land. It was true, also, on applying mixtures of common salt and superphosphate to potatoes, that it sometimes happened that the yield of tubers was less than was obtained by the superphosphate alone. In experiments with mangolds and with Swedish turnips, however, the use of salt in conjunction with superphosphate had a good effect, though the crops fell short of those obtained by using kainit and superphospate. When salt alone was used upon the turnips, it appeared to do more harm than good.

Salt as a Top-dressing.

According to Voelcker, "Common salt is used in England principally as an addition to manures for mangolds, and, mixed in equal proportions with nitrate of soda, as a top-dressing for spring wheat and barley. It is also useful on light land in dry seasons." When salt is used for the purpose of prolonging the term of growth of plants on light land, it will naturally be used as a top-dressing. But, curiously enough, it has sometimes been noticed (presumably on clay soils), even in localities where salt has been found to do good service as a fertilizing agent when ploughed under, that top-dressings of it seldom increase the crops, and that they are often distinctly hurtful. One case has been reported where 9 cwt. of salt strewn upon a Saxon acre had no visible action upon either wheat or rye, while it killed young clover. In general, it is agreed that care must be taken to use salt sparingly, and to apply it at appropriate seasons, as when neither seeds, nor sprouts, nor young plants are at hand to be injured. Instances are on record where more than 3 cwt. to the Saxon acre diminished the beet-crop, and more than 4½ cwt. diminished the yield of potatoes. In some places, 1 or 2 cwt. to the Saxon acre, applied to rye, gave the best results, while in other situations the best rye-crop was got with 6 cwt. In this instance, an application of 9 cwt. diminished the crop, and 12 cwt. lessened it still more. Here in New England, dressings of from 5 to 8 bushels of salt to the acre have often been commended; and there would seem to be little or no risk in using quantities so small as these, for it is said that as much as 20 bushels to the acre may be applied to young wheat without harm, and there are cases on record where 25 bushels have been applied to wheat with advantage. Instances are upon record where lawns have been freed from moles, without injury to the grass, by sowing salt freely. Probably muriate of potash would serve the same purpose and improve the green sward also.

There are cheap kinds of salt that are sold purposely to be used as fertilizers. It is said that they should not be applied in larger quantities than at the rate of 300 to 600 lb. to the English acre. A barrel of salt to the acre, for wheat, is one English formula.

On top-dressing grass-land with salt and nitrate of soda, Voelcker found that while the nitrate pushed on the growth of the grass, and secured a larger produce, salt checked the growth to such an extent that when as much as 10 cwt. of it were applied to an acre of stiffish land, the crop was lessened, even though nitrate of soda was used at the same time. Still, salt might perhaps sometimes be spread with advantage on spots where heaps of manure have lain, in order to check rank vegetation and make it more palatable to animals.

Experiments by Heiden go to show that, for some localities, it is better to apply salt as a top-dressing than to plough it under. He grew barley on a field of sandy loam, that had not been fertilized for 6 years, and obtained the results which are set forth in the following table: —

Lb. of salt to the square rod.	Crops harvested, in Lb. and Loth.		
	Grain.	Straw.	Chaff.
5 ploughed under	16 7	27 15	6 24
5 as top-dressing	21 27	30	5 15
7.5 ploughed under	23 8	33 9	4 14
7.5 as top-dressing	27 23	40 25	6

There can be little doubt, however, that much must depend on the character of the soil and upon the action of the salt to improve or injure its tilth, for sometimes heavy dressings of salt (20 to 40 bushels to the acre) have been applied to fallow land for the express purpose of killing weeds, with the result that vegetation is well-nigh totally destroyed for a season; but there would seem to be a risk in this case of destroying various useful micro-organisms, as well as the weeds and worms. Probably other soluble non-poisonous saline matters may retard the growth of crops as salt does, but few of them are so cheap and innocuous as common salt. (Voelcker.)

It is noticeable, withal, that sulphate of sodium may exert a physiological effect upon plants distinctly different from that produced by chloride of sodium. Thus, Hilgard has noticed in California that sugar-beets grown on soils contaminated with sulphate of soda may yield a serviceable juice, while no such result can be obtained on soils charged with common salt. This observation clearly consists with German experience in the use of potash salts, which goes to show, as Mayer insisted, that, in the long run, sulphate of potash has given much more satisfactory results than muriate of potash has.

Salt flocculates Colloid Clay.

There is another effect producible by salt which explains the good results which have often been obtained on applying it to heavy land; viz., its power of making fine particles of clay or mud cohere, as is seen when the suspended matters in turbid river-water or in mud-puddle liquor are made to subside by additions of salt. Schuebler called attention, long ago, to the fact that a mixture of salt and gypsum (a waste product from salt works) served a highly useful purpose on many clayey and peaty soils, and especially in wet seasons, both when it was applied by itself and when used in conjunction with dung or dung-liquor; though on lighter land it was apt to do harm rather than good. Gasparin, also, has called attention to the experience of farmers in France, near the mouth of the Rhone, which teaches that when moderate dressings of farmyard-manure are applied to certain clayey, saline soils of that locality, the full effect of the manure is felt at once by the crops; while on non-saline soils, equally rich in clay, very heavy dressings of manure must be applied at first, in order that the land shall be brought into proper condition.

The influence of salt to change the mechanical condition of clay has often been noticed in Holland, where a part of the injury which results when clayey polders are overflowed with sea-water has been attributed to it. But there can be no question that the action may be beneficial in very many cases where the soil is stiff and when the quantity of salt put upon it is not too large; for, like most other saline fertilizers, the salt causes the finest particles of the clay or loam to attach themselves more or less firmly to the coarser particles of sand, or what not, and thus tends to make the soil less plastic, more permeable as regards water, and more open in texture than it had been before. When sea-water is used to sprinkle dusty streets, it is noticed that the road-bed is made less muddy than is the case when fresh water has been employed for the sprinkling. For remarks on the tendency of saline fertilizers to injure seed-beds by promoting the formation of surface crusts, see Nitrate of Soda.

As has been explained under the head of Lime, common salt and other saline solutions have a considerable power to flocculate fine earth, or any minute particles that are suspended in water, much as lime does. For example, when the Mississippi water flows into the saline water of the Gulf of Mexico, much of the matter that was held suspended in the river-water is flocculated at once, so that it can subside. Such action as this is one prime cause of the formation of deltas, for the flocculation of fine mud by salt is common to all rivers that reach the sea.

A curious instance of this phenomenon was encountered at Calcutta on establishing filtering-beds of sand to purify the Hoogly water. It was found that, during the rainy season, the fine mud in the water penetrated very deeply into the filters and rapidly choked them. In the dry season this did not happen, for the suspended matters were then arrested near the upper surface of the sand. The explanation is, that, during the rainy season, the water contains a much smaller proportion of saline matter than it does in the dry season. The trouble was remedied by adding alum and salts of iron. Similar results have been obtained on applying Bischof's metallic-iron process to the purification of Mississippi water, which holds much clay in suspension. Through the action of the water on the iron, a small quantity of a soluble ferrous salt is formed which immediately coagulates the clay and causes it to settle. Conversely, where the waves of Lake Erie beat against the banks of clay upon its northern shore, the water is said to be discolored for miles out into the lake, manifestly because of the absence of saline matters to flocculate the colloid clay. It is to be remembered, however, that in soils containing calcareous matter, the addition of salt or of muriate of potash might act, not to flocculate the soil-particles, but to puddle them, as has been explained already when speaking of Alkali Soils.

Flocculation by other Saline Matters.

What is true of common salt as regards flocculation is true also of various other saline fertilizers, and it is a point always to be borne in mind that the continued use of "artificials" may change the texture of a soil, and the power of that soil to hold and to lift water. Even the saline matters which occur naturally in arable soils (notably bicarbonate of lime) do, in spite of their extreme dilution, actually exert a highly important influence to maintain soils in good tilth. Schloesing has suggested the following experiment, as illustrating this point. A quantity of moist loam, having been crumbled between the fingers to a loose condition, is shaken into a cylinder, at the bottom of which fragments of glass have been placed and covered with a layer of coarse sand. On moistening the loam with distilled water, drop by drop, a solution of the saline matters which the soil contained will be pushed downward beneath the layer of pure water, which has the upper hand, and the uppermost layers of loam will soon be left in contact with pure water, with which they finally form a mass of dough; i. e. when all the saline matters have been removed from the soil, it passes into the condition of pasty mud. Meanwhile the lower layers of the soil, although fully moistened and subjected to heavier pressure than the upper layers, exhibit no such change as to their mechanical condition, for they are still in contact with saline matters that hinder their particles from puddling.

On repeating this experiment with ordinary well-water, instead of distilled water, all the other conditions being as before, Schloesing obtained no mud at the surface of the earth. He explains his results as follows. In the fine earth, which we call loam, clay often acts as a kind of cement to hold particles of sand together. The clay gives coherence to the particles of soil, and keeps them from falling to mere dust. But this binding power of the clay is effective only so long as there is enough saline matter present to keep the clay in a coagulated condition. Whenever, by washing with pure water, the coagulating agents are removed, the clay loses more or less completely this kind of binding power, the friability of the earth disappears, and mud is formed.

Schloesing admits that not every kind of earth is suitable for the foregoing experiment, for in some soils many of the particles or granules are held together by other agencies than that of clay, and such soils are not easily puddled. Many of them will withstand the action of distilled water, as above applied. But it is still true that a large number of loams will behave in the manner indicated, and such soils are liable to be puddled at the surface when acted upon by rain, which is water that has been distilled naturally.

There are, however, noteworthy differences between the exaggerated conditions of the experiment and those to which soils are actually subjected in the fields. For although in the experiment the water is added very slowly, it may still happen that as much of it may be applied in a few hours as would amount to a layer ten or fifteen inches deep. But this would represent an enormous rainfall, such as is wholly unusual; hence the washing out of the saline matters must be more complete in the experiment than in the field. On the other hand, the beating action of rain, which must greatly promote puddling in the field, has comparatively little influence in the laboratory experiment. In the field, moreover, the rain-water, coming in showers, and in comparatively small quantities, would often be able to dissolve enough lime from the soil (chiefly as bicarbonate) to hinder deflocculation. In the case of very heavy rains, it may happen also that the soil will be so thoroughly puddled at the surface, that is to say, it will become covered with mud that is so difficultly permeable, that not enough water can percolate downward to wash out the saline matters from the layers of soil next below, so that the tilth of the soil will not be much impaired excepting at the very surface.

To the presence in soils of the natural saline matters Schloesing attributes the power of the soil to clarify turbid liquids. Were it not for the saline matters, he says, not clear sparkling water, but turbid and muddy water would flow from field-drains and springs, and be drawn from wells. In a similar spirit, Schulze had previously insisted that the soluble constituents of fertilizers and manures must often exert no inconsiderable influence upon the texture of soils. He argued that the mellow condition of soils that have been marled or heavily manured must be attributed in some part at least to the flocculating action of soluble saline matters. For that matter, it is a tenet of practical agriculture that the physical defects of stiff clays may often be corrected by applying stable-manure at regular intervals. Several writers have insisted on the influence which may be exerted by nitrate of soda, as has been explained already when discussing the fertilizing power of nitrates.

Not only do the saline matters in the soil exert an influence to preserve the mechanical coherence of the particles of earth, but it is plain, from the observations of Knop (page 214, of this Vol.), that the chemical condition of the soil undergoes marked changes whenever the saline matters are washed out from it. Lawes and Gilbert have noticed that the drainage waters from land to which ammonium salts have been applied, are apt to be especially clear and bright for some little time afterwards, because of the formation of sulphate and chloride of calcium in the soil, through the reaction of the ammonium salts on carbonate of lime. But these salts of calcium act to coagulate particles of clay.

Sodium Compounds in the Air.

As has been said, every soil contains more or less sodium, which has been derived from the disintegration of silicates, or been brought down by rain from the air. The air everywhere contains minute traces of common salt, for as the winds pass over the sea they take up mechanically, as if it were so much dust, more or less of the fine spray which is blown from the tops of the waves. Some of the salt thus lifted is carried everywhere, even to the lands most remote from the ocean, though it has been noticed by Muntz that much less salt-dust is found high up in the air than at lower levels. He insists that hay, straw and other forage grown at high elevations contain comparatively little soda, and that rain-water collected on a mountain 9,000 feet high contained no more than 0.34 mg. of salt to the litre, while on the plains at the base of the mountain there was found from 2.5 to 7.6 mg. of salt to the litre of rain-water. Hence the great craving of animals for salt in mountainous regions.

More of this salt from the spray is, of course, deposited upon land near the seaboard than upon that farther inland. At Caen, in France, 9 miles from the English Channel, Pierre found that the rain which falls upon one hectare of land in a year brings with it 57 kilos. of sodium chloride. In the immediate vicinity of Boston there is so much salt in the soil, and in the plants which grow upon it, that there is seldom, if ever, any need of giving salt to pastured cattle. Hereabouts the animals will hardly eat any of it if it is offered to them, while a hundred miles away, on the New Hampshire hills, stock kept in pastures will eat salt voraciously, and will not prosper unless occasionally fed with it. At the heart of the continent, wild animals used to travel many miles to the salt licks.

Some kinds of Plants can Bear much Salt.

The power of some plants to resist the injurious action of salt is noteworthy. It is seen familiarly in the grasses of salt marshes at the North, the mangroves of the South, and in various species of strand-plants which grow on the borders of the ocean and in the vicinity of salt lakes and springs. Several of the plants ordinarily cultivated are somewhat tolerant of salt; wheat, for example, as has been mentioned already. Asparagus, also, is a case in point. It has long been customary to put salt upon asparagus beds, " as a manure," but it is thought nowadays that the salt acts in this case chiefly to destroy weeds. The fact that the cocoa-nut tree can bear salt water has often been noticed. It is said, indeed, that on the seashore, in soils more or less saturated with salt water, — even in situations where the tide often flows around their trunks, — the trees are exempt from the attacks of beetles and begin to bear fruit in the course of 6 or 7 years, i. e., much sooner than trees which have no access to salt. The milk of the seaside-nut is apt to be slightly brackish, but the fleshy part of the nut is as thick as that in other cocoa-nuts, and it yields as much oil. As long ago as 1688, Dampier wrote as follows of an island near Sumatra: "This island, Triste, is not a mile round, and so low that the tide flows clear over it. It is of a sandy soil, and full of cocoa-nut trees. The nuts are but small; yet sweet enough, full, and more ponderous than I ever felt any of that bigness, notwithstanding that every spring-tide the salt water goes clear over the island."

Dyer, in field experiments made in England, noted that the chief lesson taught by his results is the high value of salt as a dressing for cabbages when a sufficiency of other suitable manurial ingredients is present. Salt seemed to be needed to bring out the full action of phosphates and nitrates. Even the good effects obtained by using kainit, in conjunction with phosphates and nitrate of soda, were attributed to the salt which it contains.

In the vicinity of Boston, some market gardeners are said to have found it advantageous occasionally to pump brackish water from the tidal rivers for irrigating cabbages, cauliflowers, tomatoes, celery,[1] horseradish and onions. For these particular crops, the saline water has even been preferred to fresh water, and it is reported that it has sometimes been applied so freely that the ground on drying has become white with salt. Mature plants of the kinds above mentioned are not injured; but it is said that the salt water would kill even these plants if it were applied to them when young. Melons are said to be killed by it at all times.

This power of the mature plant to resist the action of salt better than seeds or young plants can resist it, has been illustrated by methodical experiments. Becquerel, for example, found that while the seeds of wheat and barley were more readily injured by salt than those of ray-grass and white mustard, the young plants could bear larger amounts of salt when they became more fully developed.

According to Heiden, the susceptibility of seeds to salt may perhaps explain in some part the repute in which salt is held as a means of destroying weeds. For, when applied to the land some little time before a crop is sown, salt may possibly kill many weed-seeds and cripple so many of the weeds which do germinate, that the crop proper may with comparative ease gain full possession of the field. He urges in general that for the best advantage of a crop, salt should be applied to the land either some little time before seeding, or so long after the crop has started, that the plants may have become strong enough to resist its hurtful action.

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[1] Compare Bulletin of the Bussey Institution, II, 370.

It is safe to say that the above-mentioned plan of irrigating crops with brackish water could hardly be persisted in for any great length of time on one and the same piece of land. Voelcker tells of land, purposely irrigated with sea-water, under the mistaken idea of improving it, which was rendered unproductive for several years, and it is a matter of record that long experience at the South of France has shown that any soil which becomes visibly covered with a slight incrustation of salt in times of drought is improper for cultivation unless special pains are taken to prevent the surface from becoming dry. Even as a temporary device, great care would need to be exercised in using saline water for irrigation. Several instances have been reported in England of attempts to irrigate land with sea-water which turned out to be utter failures. The land was made sterile for two or three years. As Stood has suggested, although brackish water may sometimes promote the growth of crops temporarily, the continuous use of such water would assuredly do harm. He admits that irrigation with slightly saline water may do good during those months when rain falls so frequently that the ground is kept fairly moist, but he has observed in dry summer weather that the saline solution becomes so concentrated by evaporation that enough salt is brought to the surface of the land through capillary action to kill the crop. Any water which contains more than one-thousandth part of salt cannot be recommended for irrigation, although his experiments show that water which contains as little as one two-thousandth part of salt may still exert an appreciable action in setting free fertilizing matters in the soil. Storp has noticed that a solution of salt as weak as the one last mentioned hindered the germination of barley, while a one-thousandth solution arrested the germination of this grain well-nigh completely.

The French chemist, Plagniol, insisted long ago that soils containing more than 2 % of salt are unfit for the growth of any plants other than samphire, saltwort or the like, and that even these saline plants cannot thrive in soils that contain 5 % of salt. But Dehérain maintains that the teachings of French experience indicate that soils which are habitually moist may contain as much as 2 % of salt without being unfitted to bear agricultural crops, although in soils that dry out easily, the presence of 1 % of salt is sufficient to cause sterility. Gasparin admitted that soils which contain no more than 0.02 % of salt can yield good crops of wheat, but that ten times this amount is more than wheat can bear.

It is true, however, that there are districts at the south of France where, by taking care to mulch the land with rushes when the grain is sown, excellent crops of wheat are grown habitually on soils so saline and alkaline that they cannot be ploughed when moist because the furrows would be puddled, and would dry out to unbreakable clods. In case dry weather should set in, in the spring, the root-crowns of wheat-plants standing in this soil would be crushed by the hardening of the land if no pains had been taken to provide a mulch to keep the surface moist. (Gasparin.)

All "Salts" are Dangerous.

It is evident that experiences such as the foregoing teach a very emphatic lesson as to the danger which must attend the use of any kind of saline fertilizer. When common salt, or muriate of potash (as has been explained already), or any analogous substance, is strewn upon the land, each particle of the salt will unite with the water in the soil to form a concentrated solution which might act to destroy seeds or young plants. This danger will be done away with, of course, if the all-too-concentrated solution can be adequately diluted either by the presence of abundant moisture in the soil, or by rains which may fall between the times of strewing the fertilizer and sowing the seed. In order to be safe, the saline fertilizers should be applied months before the time of sowing seeds, or just before rain, or long enough before seeding to allow for the coming of rain; or the salt may be applied to a growing crop in rainy weather. In any event, too large a dose of the saline matter must be avoided lest the plant should finally suffer in time of drought when the solution brought to it and to the surface of the soil by capillary action becomes too much concentrated through evaporation. It has been said of Utah, that "The alkaline nature of the soil is injurious to vegetation, though potatoes, squashes and melons are made sweeter by a small admixture of it."

It was thought formerly in England that salt must be particularly useful for mangolds, since the beet grows naturally upon the seashore. As has already been set forth, salt was frequently applied at one time to this crop, and many statements have been published in evidence of its utility. After studying the question with care, as has been stated on a previous page, Voelcker made the following statements: "If I am not mistaken, salt seldom produces any good effect upon mangolds on stiff, calcareous clays; whilst on light, sandy soils, if my experience teaches me true, it is generally applied with great success. It would be wrong to say, in a general way, that salt is of no use to mangolds; all that can be said with propriety of my experiments is, that in many of them salt did not produce a decidedly beneficial effect upon that crop. . . . That salt is often injudiciously applied to the land can hardly be denied; but, at the same time, its utility on light, sandy soils, I think, cannot be gainsaid. Some of my own experiments appear to countenance this view, and to agree well with the experience of many intelligent light-land farmers. . . . It would appear, from some of my experiments, that on poor, sandy soils, as large a dressing as 9 cwt. of salt to the acre may be used with advantage, though I do not recommend so large a dose. Probably 4 to 5 cwt. is a sufficient dressing on the lightest sands; and on good, sandy loams, and warm, friable turnip-soils, 3 cwt. will probably give a better result upon mangolds than a larger dose. . . . Occasionally salt does more harm than good, not only to mangolds but to other crops as well; and I have no hesitation in saying that, in cold summers, even a moderate dressing is injurious to mangolds, when the crop has to be grown on a cold, calcareous clay, or on similar stiff soils. . . . It appears from my experiments on a poor, sandy soil, that salt (used in conjunction with farmyard-manure) has a very marked influence in promoting the development of the leaves of beets. On light, sandy soils, mangolds are liable to pass too rapidly through all the stages of their growth, and to yield a poor crop. If I am not mistaken, salt checks this tendency in a great measure, and, by keeping the tops in a healthy growing condition, contributes ultimately to a larger produce of roots on light land."

Salt as a Germicide.

It is still an open question as to how much good, if any, is to be attributed to salt as a means of destroying fungi and insects when used in such comparatively small quantities as are commonly applied to the land. It is not impossible that there may be something in the idea, since it is a well-known fact that strong brine will destroy many fungi and spores of fungi that are injurious to plants.

Some English farmers have maintained that salt is a far more efficient agent than lime for destroying slugs. It has even been claimed that 1 cwt. of salt to the acre, sown upon land in which slugs have been noticed, will destroy them completely, without injury to the wheat. Others have urged that salt scattered upon the land at the rate of 4 or 5 bushels to the acre, before the crop is sown, is certain to destroy the slugs when they come forth at night, or after a shower, to feed. Another receipt reads: "Sow salt over wheat, 6 bushels to the acre. On a moist morning it will destroy the worms and slugs, while on light soils it tends to shorten and brighten the straw, and to increase the yield of grain. On clay lands it is said to render the soil too moist, and to give an unhealthy look to the young plants." So, too, a mixture of 2 cwt. of salt and 1 cwt. of guano to the acre, sown at early dawn after a still, dewy night, upon young mangolds, has been found an effective means of destroying slugs, which are apt to feed upon the tender seed-leaves of the beets, to the serious injury of the crop.

In England, salt is often sown upon lawns, at the rate of 10 bushels to the acre, for the purpose of destroying earth-worms; or, at the least, to prevent the formation of worm casts. Here in Massachusetts an instance has been reported of the successful use of salt upon grass that had been injured by worms (grubs?) eating the roots. Applied at the rate of 40 bushels to the acre, the salt killed the worms and caused the grass to grow vigorously. As a remedy for cut-worms, salt has sometimes been strewn upon the ground before spading it; but muriate of potash, or even nitrate of soda, would probably answer the purpose better. It should be noted, moreover, that, as the experiments of Geubel show, solutions of salt need to be rather strong, in order that they may destroy slugs, or worms, or insects. In view of the speedy and enormous dilution to which the comparatively small quantities of salt ordinarily applied for fertilizing purposes must be subjected in the soil, it is hardly possible that many slugs can be killed by them unless the conditions happen to be particularly favorable. It is not improbable, however, that even dilute saline solutions may be so distasteful to the worms that they may be somewhat hindered from attacking the crops.

The following statement as to the usefulness of salt was made a few years since by one of the most successful planters at the South.

"I have used salt," he says, "for fifteen or more years. I find it essential to success on all lands like mine, and most of the cotton-lands are like mine. 300 lb. of salt and 200 lb. of plaster are almost a total preventive of rust, which is one of the worst enemies the planter has to contend with. Salt makes cotton bear longer in the season, and stand drought better; it increases the quantity, and improves the quality. It acts equally well on corn, oats, and other grains, and it toughens wheat-straw so that there is less waste from ears breaking off when the crop is cut."

But here again chloride of potassium might perhaps do better service than chloride of sodium.

Common salt is said to have been used at one time to a considerable extent in Switzerland as an addition to the liquid that drains out of the dung-heaps into pits which are made to receive it. The mode of action of the salt in this case has not been explained, but good effects are said to result in practice from its use. Possibly it acts as a preservative by hindering fungi from acting on the manure. Probably some of the Stassfurt products would be better for this purpose than salt.

In speaking thus of the possible utility of salt as a germicide, it needs to be borne in mind that, in field practice, too heavy dressings of salt would be apt to do harm, by destroying the useful micro-organisms which act to keep land sweet and mellow; that is to say, which prevent the humus of the soil from becoming acid. The remark of Voelcker, just now cited, that in cold summers salt often does harm on stiff soils, would seem to point to this conclusion; and so do the statements of other observers, who have noticed that salt water sometimes makes land hard and sour.

Action of Salt and Lime in Soils.

The action of a mixture of salt and lime in compost-heaps has already been explained as due to the formation of a small quantity of sodium bicarbonate, which causes the peat or other organic matter to ferment. Cases are upon record where exceptionally strong and heavy wheat has been grown upon clover-sod that had been dressed, at the rate of 25 to 35 bushels to the acre, with a mixture of 1 part salt and 2 parts lime that had been left in heaps for two or three months, with occasional stirring, before applying it to the land. A particularly advantageous method of using the mixture is said to be to mix it with water before spreading it upon the land; 10 or 15 tons of water were used to the acre, together with the 25 or 35 tons of the salt and lime mixture.

In like manner, salt mixed with lime has occasionally been found to be a useful application upon reclaimed and drained peat-bogs, and upon the so-called "mosses" of Lancashire. The mixture is said to destroy the mossy character of the surface of such bogs, and to serve as an excellent preparation for a first crop of potatoes. Indeed, there are upon record not a few farm experiments where the application of lime and salt to the land has increased the yield of crops. As has been said already, chloride of potassium would perhaps be better than chloride of sodium to use with the lime; and, in so far as concerns the compost-heap, it would probably be more advantageous to buy caustic soda outright, or, better still, to buy caustic potash, which is equally strong with soda as an alkali, and is a true manure into the bargain.

It is to be noted moreover that the power of salt and carbonate of lime to react upon one another when in presence of carbonic acid, with formation of sodium carbonates, may explain a certain class of cases in which salt has proved efficacious as manure. In this way, when salt is applied to a limestone soil, there may really be given to the land a dressing of carbonate of soda, and of the efficacy of this substance to promote the decay of humus and the disintegration as well as the binding of soils, there can be no question.

Indeed, it is hard to escape the conviction that there must be soils the fertility of which is promoted in this way. For it is seen in alkali deserts that the reaction between salt and limestone does really occur in nature; the only trouble in this special case being that the reaction is too strong for the purposes of agriculture. So much of the sodic alkali has been formed in these cases that plants, or, at the least, the texture of the soil, have been destroyed by it. But inasmuch as it is known that small quantities of the alkaline soda-carbonate may be beneficial both to plants and to some soils, it seems plain that this substance must sometimes conduce to fertility, even when it has been formed naturally. It is difficult not to believe that there are somewhere in the world localities where the reaction between salt and limestone may occur habitually in the proper degree. One merit of the soda-carbonate is, that it can dissolve to an appreciable extent phosphate of iron such as is formed in the soil. Voelcker observed, in several instances where fertilizers of various kinds were applied to permanent pastures, that applications of mixed lime and salt considerably increased the yield of grass, while salt used by itself diminished the crop.

Alkali Soils.

Reference has already been made, under Potash, to the fact that the action of carbonate of soda may be extremely harmful when too much of it is present in a soil. There are to be found, indeed, in many countries where the rainfall is somewhat scanty, patches of low-lying land which contain so much of this alkali that their cultivation is often extremely difficult or even impossible, in case the soil is naturally clayey or impermeable, unless pains are taken to remove or to destroy the carbonate. As will be explained under Irrigation, the soluble alkali may be completely removed from any land which is provided with tile-drains and artificially watered; and, as has been stated already, it is often possible to decompose the carbonate, sufficiently for practical purposes, by applying gypsum to the land.

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